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GRAPHIC AND QUANTITATIVE COMPARISONS OF LAND TYPES[1]

J. O. VEATCH[2]

MOST descriptions of land surfaces are qualitative. Geographers and geologists have been adept in describing how and why land surfaces differ in their physiognomy, but not in stating to what degree they differ. The need for more precise, or quantitative, descriptions is evident when closely related, or very similar land types are compared, and when land types are being evaluated for some particular use as, for example, a type of farming.

As a consequence of reflections such as the foregoing, and as an attempt to supply a need for quantitative comparisons in connection with recent research in the differentiation of natural land types and in the evaluation of kinds of land in relation to agricultural use, the author has devised a scheme for the graphic comparison of slopes and has developed some additional ideas for comparing land on the basis of the number and areal extent of significant land components.

The scheme for the graphic comparison of topographic components is based upon the premise that any given area of natural land surface has inequalities. There is no part of the earth's land surface that is absolutely flat or entirely devoid of relief. Local differences in elevation may be only a few feet, or at the other extreme, the relief features may be of mountainous magnitude, but in either case the surface area of any tract of land is composed of three parts, *viz.*, (1) the *highland*, relatively level, as the top of a knoll, the crest of a ridge, the table land of a high plateau; (2) the *lowland*, as a valley bottom, a basin, a gentle swale or any other kind of depression; and (3) the *slopes* connecting 1 and 2. The respective percentages of these three components constitute criteria for the evaluation of land; and further, the expression of these components in some quantitative way may be very useful in purely academic comparisons of separate physiographic divisions. The slope component may be subdivided into classes on the basis of range in gradient and the percentage of

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[2] Research Associate in Soils.

each gradient class determined separately and so furnish additional quantitative data of value. For the purpose of making a graph, the separate slope classes may be integrated and slope expressed as a single line. The number of slope classes and the gradient value assigned to each class may vary in accordance with the purpose of the comparisons and of course should be in harmony with the physiographic type of land surface and local differences in altitude.

Data for constructing graphs can be obtained from contour maps by linear traverse measurements or from actual areal measurement in the event that the latter is practicable. If more accurate and more complete data are desired than can be obtained from the ordinary contour map made on a scale of approximately an inch to the mile with a contour interval of 10 or 20 feet, special field surveys will have to be made. These may consist of linear traverses, run at close intervals, in which the linear extent and frequency of any minor land component may be recorded, or they may be complete areal surveys from which the acreage of any particular land component may be computed on the basis of planimeter measurements.

The illustrative graphs which accompany this paper are based on data obtained by linear measurements from selected U. S. Geological Survey contour maps. The degree to which percentages obtained in this manner represent actual areal extent of the separate components in any given area will depend, of course, upon the interval between the lines of traverse. Four classes of slopes were recognized which were assigned, respectively, average gradient numbers of 5, 10, 20, and 30. Slopes less than 3% in gradient were included as level whether in upland or lowland divisions. In order to expedite the measurement of the slope classes, the contour lines were grouped on the basis of the number per linear mile that fits the range in gradient values assigned to the five classes of slopes. The line of inclination, or the number which represents the integration of the slopes, is obtained by multiplying the percentage number of each class of slope by its gradient average, thence totaling the results and dividing by four.

The following method of plotting the lines was adopted. A square was drawn, a side of which was equal to the total slope percentage distance on the graph, and then a value assigned to its combined right vertical and basal sides equal to one-fourth of the highest gradient value times 100. Thus, if the highest gradient value is 30, the two sides will be 750, and beginning with 0 in the upper right hand corner of the square any integrated slope number can be plotted according to the proportional distance between 0 and 750. For example, a slope value of 375 would be represented by a line drawn from the end of the highland level leg to the lower right hand corner of the square.

The areas illustrated by the graphs were chosen more or less at random but at the same time with a purpose of testing the mechanical practicability of the scheme.

Fig. 1 represents a comparison of glaciated parts of the Allegheny Plateau in southern New York, with unglaciated parts in adjacent northern Pennsylvania. The several areas are fairly comparable in elevation above sea-level. The effect of glaciation is strikingly shown.

The decrease in the length of the slope line and corresponding increase in the percentage of level highland and level valley land is probably in proportion to the degree of glaciation and amount of deposition of drift this being least in the Ithaca quadrangle and greatest in the Clymer. Tabulations reveal no great difference in the number of streams and valleys in the glaciated and unglaciated parts of the plateau.

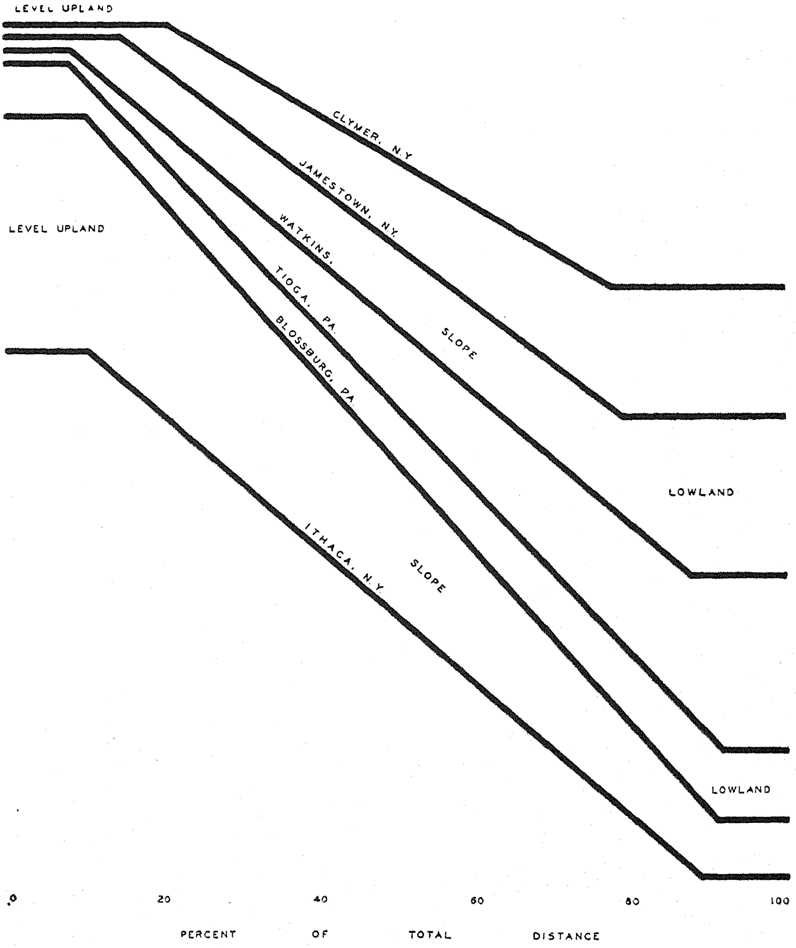

FIG. 1.—Graphic comparison of the topography in glaciated and unglaciated parts of the Allegheny Plateau.

Fig. 2 represents a comparison of glaciated surfaces in regions of crystalline rocks in Maine and in the western part of the Upper Peninsula of Michigan. A very marked contrast in the physiognomy of the two areas is evident. The pre-Glacial topography of the Michigan area was less mountainous and had less relief or the valleys were more completely filled with drift as compared with the Maine area. A tabulation shows 120 streams per hundred miles of traverse in Maine and only 41 in Michigan. The lowland leg of the Buckfield graph is composed almost entirely of stream valley lowland and that of the Perch Lake almost entirely of shallow swampy basins or "muskeg".

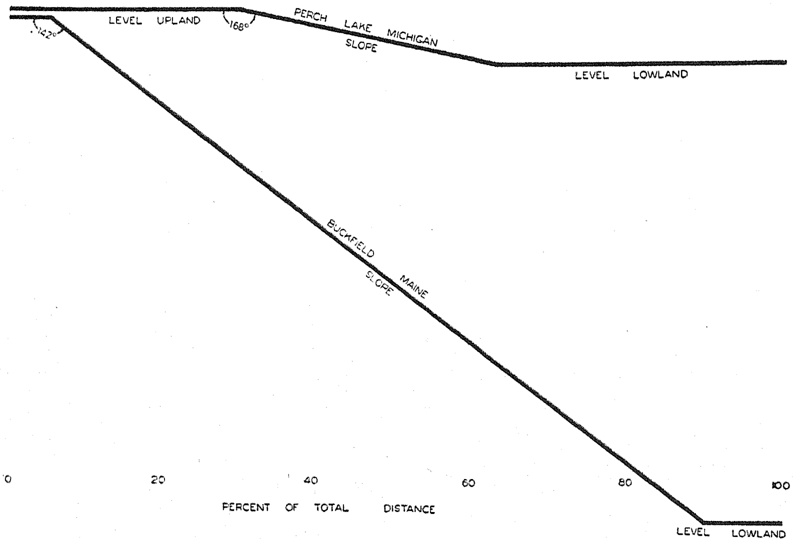

FIG. 2.—Graphic comparison of the topography of areas in Maine and in Michigan.

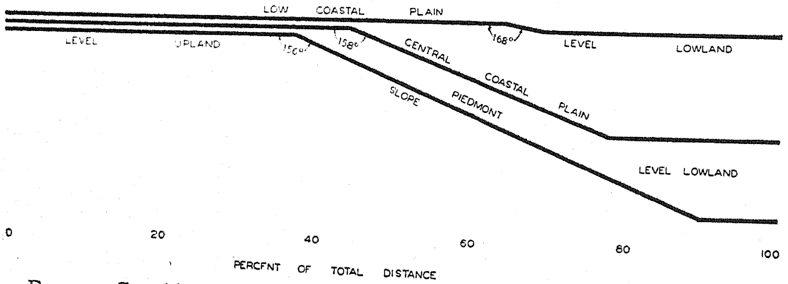

FIG. 3.—Graphic comparison of the topography of areas in the Piedmont Plateau and Coastal Plain of Georgia.

Fig. 3 is a comparison of the lower part of the Piedmont Plateau, near Augusta, Georgia, with the central part of the Atlantic Coastal Plain and the lower part of the Coastal Plain near the Georgia-Florida line and a few miles inland from the Atlantic Ocean. The differences in the amounts of level upland and level lowland in the Piedmont and in the Coastal Plain are concisely shown. The number of streams, according to tabulations of frequency, was 132 per hundred miles of traverse in the Piedmont, 59 in the middle Coastal Plain, and 22 in the lower Coastal Plain.

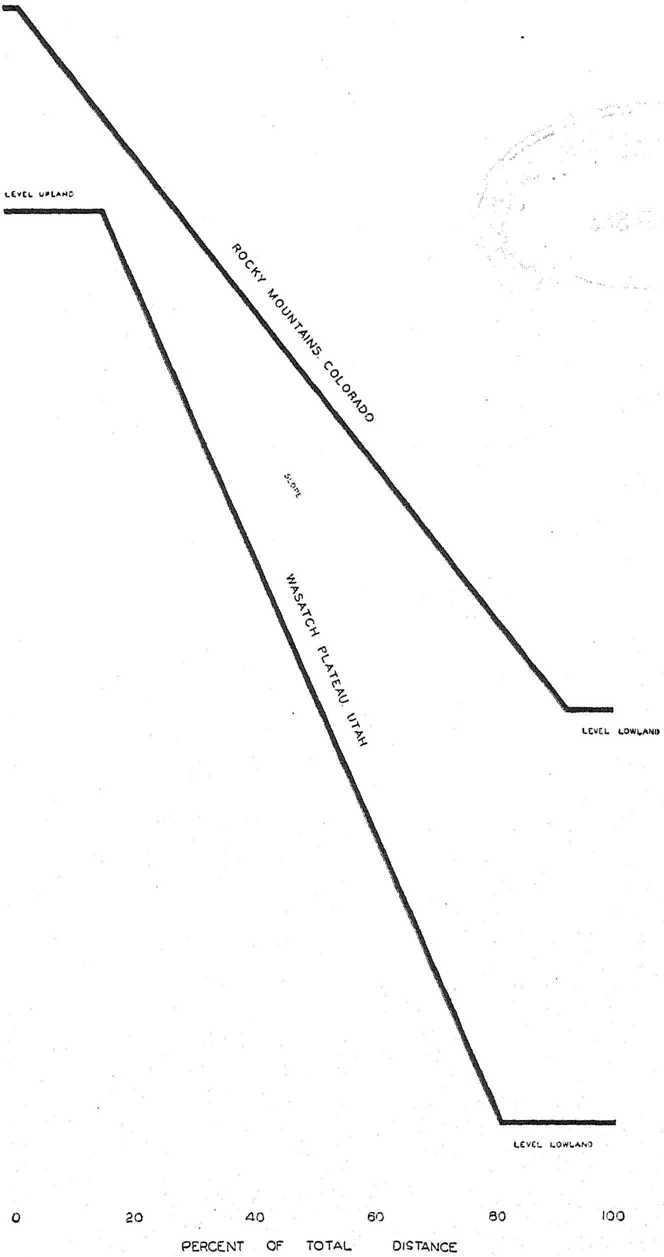

FIG. 4.—Graphic comparison of areas in the Wasatch Plateau, Utah, and in the Rocky Mountains of Colorado.

Fig. 4 is a comparison of an area in the Wasatch Plateau in central Utah with one in the Rocky Mountains in central Colorado. The difference in the two graphs is an expression of the greater maturity of stream dissection, a greater percentage of smoother and less precipitous slopes, and a smaller areal extent of level land on ridge crests in the Rocky Mountain area.

Quantitative data for the comparison of land types may also be expressed in tabular form. The criteria, or particular land components selected for measurement, should be those that have importance whether in the taxonomy of land classification or in relation to economic uses of land. They will not be the same everywhere but will vary according to different natural and economic geographic divisions.

An illustration of a quantitative comparison is given in Table 1.

TABLE 1.—*Quantitative comparisons of selected morainic land types in Michigan.*

Moraine and location	Swamp, % acreage	Swamp frequency	Stream frequency	Lake frequency	Clay land %	Sand, %	Sandy loam %
1. Defiance, Washtenaw Co.	7.5	45	73	4	83	2	7
2. Defiance, Hillsdale Co.	8.5	60	80	8	71	1.5	17
3. Mississinawa, Washtenaw and Jackson Co.	23	119	8	27	1	5	62
4. West Branch, Ogemaw and Roscommon Co.	4	19	9	6	0	81	13

The land data are not complete but even so the table reveals such marked differences that the three separate morainic areas can hardly be considered as the same kind of land except from the point of view of origin. Probably only very minor subtype differences exist between 1 and 2.

Frequency of occurrence of selected features expressed as the number per hundred miles of traverse has both taxonomic and practical significance. The comparative numbers of streams, lakes, and swamps constitute specific criteria throughout the glaciated region of the Great Lakes. The frequency of slopes of more than a 10% gradient and the number of depressions which might constitute "frost pockets" would be significant in the evaluation of land for orchards in southern Michigan.

As a further illustration of the idea of quantitative comparison of land, the comparative amounts of (1) black or dark brown prairie soil, (2) the "gray" prairie soil, (3) the timberland or forest soil, (4) wet upland, and (5) number of streams would comprise the principal data for the differentiation of the major natural land types in the glaciated prairie region of the central United States.

A COMPARISON OF SOME METHODS USED IN EXTRACTING SOIL PHOSPHATES, WITH A PROPOSED NEW METHOD[1]

C. L. WRENSHALL AND R. R. MCKIBBIN[2]

THE power of weakly acid solutions to extract a portion of the soil phosphate has been made the basis of a number of methods of estimating the capacity of a soil to supply the phosphorus requirements of growing plants. It is well known that these methods give valuable results, especially when the limit values are carefully worked out for the soil types and climatic zones on which they are used. The results obtained are often highly correlated with the results of field trials, pot tests, and the Neubauer (6)[3] seedling method. The fact that such methods are of value indicates that the readily soluble, inorganic phosphate in the soil constitutes the chief source of phosphorus available to plants.

It is also common knowledge among workers in this field that instances arise in which acid extraction methods give a false impression of the power of a soil to supply phosphorus to crops. This seems especially true for soils of calcareous nature. Thus Das, (1), McGeorge and Breazeale (5), and others have found it necessary to devise other means of detecting phosphorus deficiency in calcareous soils, and Thornton (7), in a recent comparison with the seedling method, found that acid extraction removed too much phosphorus from neutral and calcareous soils.

It was thought that the deficiencies of many or all of the present acid extraction methods might be at least partly due to the fact that they involve extracting the soil with solutions containing large quantities of ions which are relatively rare in the soil solution. In general, the calcium ion is much more abundant in soil water than is either the ammonium or potassium ion, and the sulfate ion is normally the predominating anion. If the ions present have specific effects on the amount of phosphorus extracted, it would seem logical that the ions present in any solution used to extract the fraction of soil phosphorus most available to plants should be those chiefly present in soil solutions.

The present investigation was undertaken with the intention of comparing the power to extract soil phosphate of acid solutions containing calcium ion and sulfate ion with the power of the extracting solution of Truog (8) and that of Lohse and Ruhnke (4). Such a comparison would demonstrate any differences due to the different cations present. Having in mind the idea that the solutions containing calcium ion should more nearly approach natural extracting

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[1] Contribution No. VI from the Macdonald College Pasture Committee, Professor L. C. Raymond, Chairman. Macdonald College Jour. Ser. No. 58. Received for publication March 25, 1935.

[2] Graduate Assistant and Assistant Professor of Agricultural Chemistry, respectively.

[3] Reference by number is to "Literature Cited", p 518.

conditions in the soil, it was hoped that their use might lead to a better means of characterizing soils on the basis of available phosphorus. Further work, in the form of standardization against field and pot tests, is projected.

EXPERIMENTAL PROCEDURE

Preliminary experiments were directed toward the preparation of sulfuric acid solutions containing calcium sulfate, which would afford proper comparison with the other methods from the standpoint of both intensity and capacity factors of acidity. The following solutions were adopted for use.

1. *$Ca(HSO_4)_2$.*—For direct comparison with the Lohse and Ruhnke extraction: Calcium, 300 p.p.m., sulfate (SO_4), 1,440 p.p.m. (theoretically $Ca(HSO_4)_2$), pH 2.0. The change in the pH value of this solution on extraction of a soil is usually negligible, and in case there is appreciable change it corresponds closely to the change in the pH value of a $KHSO_4$ solution of the same normal concentration and pH.

2. *Quebec solution.*—For direct comparison with Truog's extraction: Calcium, 500 p.p.m., sulfate, 1,270 p.p.m., pH 3.0. This solution contains 1.70 grams of $CaSO_4$ per litre. Saturated $CaSO_4$ contains about 1.76 grams per litre at 0° C (3). Using this solution, the change in pH value during extraction of a soil was found to correspond closely to the change in the pH value of Truog's solution on extraction of the same soil.

Comparisons of the extracting powers of the different solutions were made on a variety of soils. All soil samples were air-dried and screened through a 20-mesh sieve. The phosphate contents of extracts were determined by the Deniges (2) colorimetric method as modified by Truog and Meyer (9). Color comparisons were made in a Kennicott-Campbell-Hurley colorimeter, which has been found very suitable for this work, particularly when the colors were faint. Results have been expressed as p.p.m. of elemental phosphorus in the soil.

All pH determinations were made electrometrically, using the hydrogen electrode and calomel half-cell.

DATA AND DISCUSSION

The extracting power of the $Ca(HSO_4)_2$ solution was compared with that of the $KHSO_4$ solution of Lohse and Ruhnke on a number of soil samples taken from fertilized and unfertilized pasture soils of the brown forest soil type. The extractions with the $Ca(HSO_4)_2$ solution were of five minutes duration for direct comparison with the Lohse and Ruhnke procedure. The results are recorded in Table 1.

These data show that in 5-minute extractions the $Ca(HSO_4)_2$ solution extracted much less phosphate phosphorus than the $KHSO_4$ solution in all cases. This consistent difference could only be attributed to the different action of the potassium and calcium ions, as the solutions were strictly comparable in other respects.

By testing with potassium thiocyanate it was seen that the $KHSO_4$ extracts contained appreciable amounts of ferric iron, and the $Ca(HSO_4)_2$ extracts a slight trace. A test with acidified calcium sulfate solutions of graded pH showed that some ferric iron could be extracted from soils of this type by all solutions of pH 2.60 or less.

A test of the course of extraction of the $KHSO_4$, $Ca(HSO_4)_2$, Truog, and Quebec solutions was made, using soil 5 A. The results are recorded in Table 2, and expressed graphically in Fig. 1.

TABLE 1.—*Comparison of $KHSO_4$ and $Ca(HSO_4)_2$ as extracting agents.*

Soil	P extracted in p.p.m. of soil	
	$KHSO_4$	$Ca(HSO_4)_2$
1 A	25	15
1 B	17	7
1 C	18	7
2 A	56	40
2 B	24	9
2 C	20	6
3 A	38	18
3 B	25	9
3 C	25	5
4 A	39	19
4 B	25	11
4 C	25	8
5 A	53	34
5 B	28	14
5 C	28	9
6 A	52	42
6 B	31	10
6 C	27	9

TABLE 2.—*Influence of duration of extraction on the amount of phosphorus extracted by different solutions from a brown forest soil.*

Duration of extraction in minutes	P extracted in p.p.m. of soil			
	At pH 2.0		At pH 3.0	
	$KHSO_4$	$Ca(HSO_4)_2$	Truog	Quebec
5	50	34	20	17
10	60	42	—	—
15	—	—	25	21
20	78	56	—	—
30	92	67	28	23

These data demonstrate clearly the drastic action of solutions at pH 2.0. In the case of the $KHSO_4$ solution and of the $Ca(HSO_4)_2$ solution sufficient sesquioxides were dissolved in the half-hour extraction to form a very appreciable precipitate when the extracts were neutralized with NH_4OH. Furthermore, it is evident that no distinct fraction of the soil phosphate is dissolved in 5 minutes, nor even in the half-hour extraction, as phosphate is being dissolved at a considerable rate throughout the range of duration studied. It appears that the values obtained on these soils with solutions at pH 2.0 must be very arbitrary.

In the cases of the Truog and Quebec solutions, on the other hand, the rate of extraction of phosphorus falls off rapidly after the first 5 minutes, and after 30 minutes phosphate is being dissolved at a very slow rate. No trace of ferric iron could be detected in these extracts.

The specific action of different ions is also illustrated in these data. Comparing $Ca(HSO_4)_2$ with $KHSO_4$, and Quebec with Truog, it is apparent that the solutions containing calcium dissolve less phosphate at all stages of the extractions. The difference between the amounts extracted becomes greater as the extractions proceed in each case; and there is no evidence that a common value will ever be approached. The pH values in each set of comparisons correspond so closely that there seems to be little doubt that the existing differences are due solely to the different actions of the cations present.

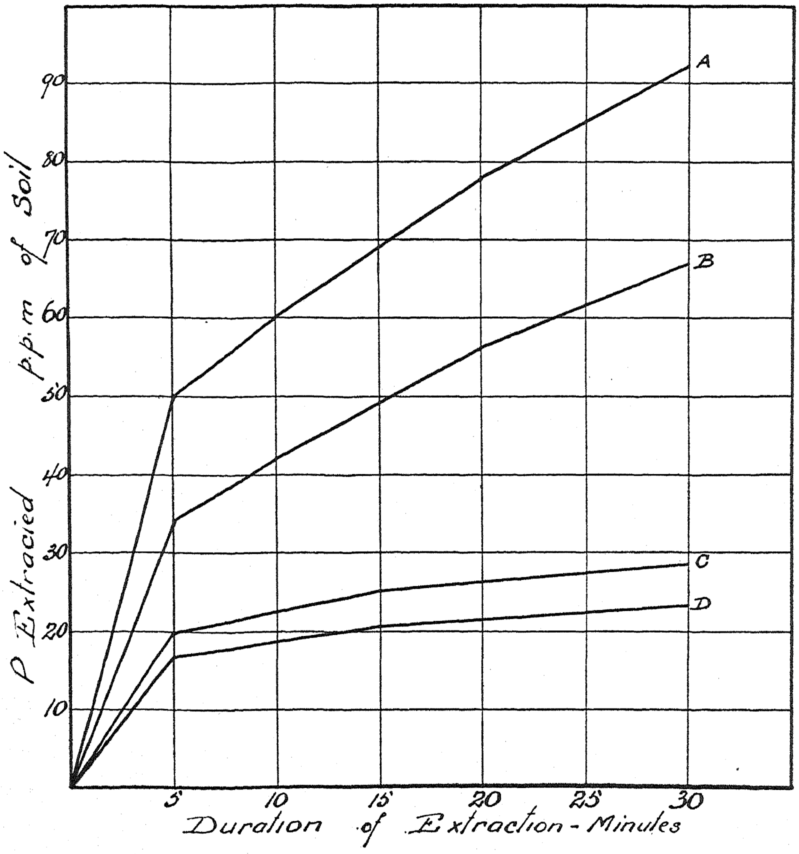

FIG. 1.—Rates of solution of soil phosphate in different solvents.

Key	Solution	Initial pH value	pH value after ½ hour extraction
A	$KHSO_4$	2.00	2.05
B	$Ca(HSO_4)_2$	2.00	2.04
C	$(NH_4)_2SO_4+H_2SO_4$	3.01	3.59
D	$CaSO_4+H_2SO_4$	3.00	3.56

A number of soils of widely different nature were extracted with the Truog and Quebec solutions, and the phosphorus determined in the extracts. The results obtained are presented in Table 3 and are

TABLE 3.—*Comparison of Truog and Quebec extractions of a variety of soils.*

Description of soil	Soil designation	P extracted, p.p.m. of soil		% difference $\frac{(T-Q)100}{T}$	Final pH of extract		pH of soil
		Truog	Quebec		Truog	Quebec	
Brown earth pasture soils, unfertilized, surface ½ in. layer	R 1	12	12	0	3.50	3.46	5.7
	R 2	17	10	41	3.56	3.60	5.5
	R 3	18	12	33	3.27	3.27	5.6
	R 4	17	15	12	3.44	3.44	5.5
	D 1	8	6	25	3.24	3.24	5.3
	D 2	13	9	31	3.27	3.27	5.4
Brown earth pasture soils, top dressed with superphosphate, surface ½ in. layer	R 5	35	24	31	—	—	5.5
	R 6	28	23	18	—	—	5.6
	R 7	102	80	22	3.53	3.56	5.5
	D 3	15	12	20	—	—	5.4
	D 4	90	53	41	—	—	5.3
	E 1	25	19	24	—	—	5.2
Brown earth cultivated soils, relatively high in lime and nearly neutral, unfertilized, surface layer	A 9	84	47	44	—	—	7.0
	A 13	76	42	45	—	—	6.0
	A 25	80	47	41	—	—	6.5
	A 27	85	50	41	3.20	3.23	6.7
	A 35	80	48	40	3.20	3.25	6.4
	A 37	76	43	43	—	—	6.7
Brown earth calcareous subsoils between 16–24 in.	A C-3	39	6	85	4.12	4.30	8.0
	A D-3	52	13	75	3.38	3.41	7.2
	A E-1	20	2	90	6.28	6.11	7.9
Virgin podsols, A_1 horizon unfertilized	P 1	16	15	6	3.04	3.02	3.0
	P 2	46	40	13	—	—	3.2
	P 3	50	44	12	—	—	4.4
	P 4	45	40	11	—	—	4.3
Cultivated podsols, S 0–8 in., D 16–24 in.	S 4	23	20	13	3.10	3.08	5.4
	D 4	6	5	17	3.22	3.20	5.2
Unfertilized black muck, A 0–12 in., B 12–24 in.	60 A	15	9	40	4.70	4.65	6.3
	109 A	15	14	7	—	—	5.7
	56 A	35	35	0	—	—	3.6
	56 B	10	11	—10	—	—	3.8
	95 A	16	13	19	3.56	3.42	6.6
	35 A	7	11	—57	—	—	4.2
	35 B	5	9	—80	3.83	3.64	5.1
Fertilized black muck, A 0–12 in., B 12–24 in.	C 1 A	112	98	13	—	—	6.7
	C 1 B	18	21	—17	—	—	6.1
	C 2 A	196	185	6	—	—	6.2
	C 2 B	15	15	0	—	—	6.5
	C 3 A	490	430	12	—	—	7.2
	C 3 B	86	92	—7	—	—	6.7
	C 4 A	260	200	23	5.20	5.23	7.0
	C 4 B	32	34	—6	—	—	6.5

grouped according to the nature of the soils. The pH values of the soils, the percentage difference between the phosphorus results, and, in a number of cases, the final pH values of the extracts are also included in the table. Percentage difference between the results by the two methods was calculated thus:

$$\text{Percentage difference} = \frac{(\text{Truog result} - \text{Quebec result})\ 100}{\text{Truog result}}.$$

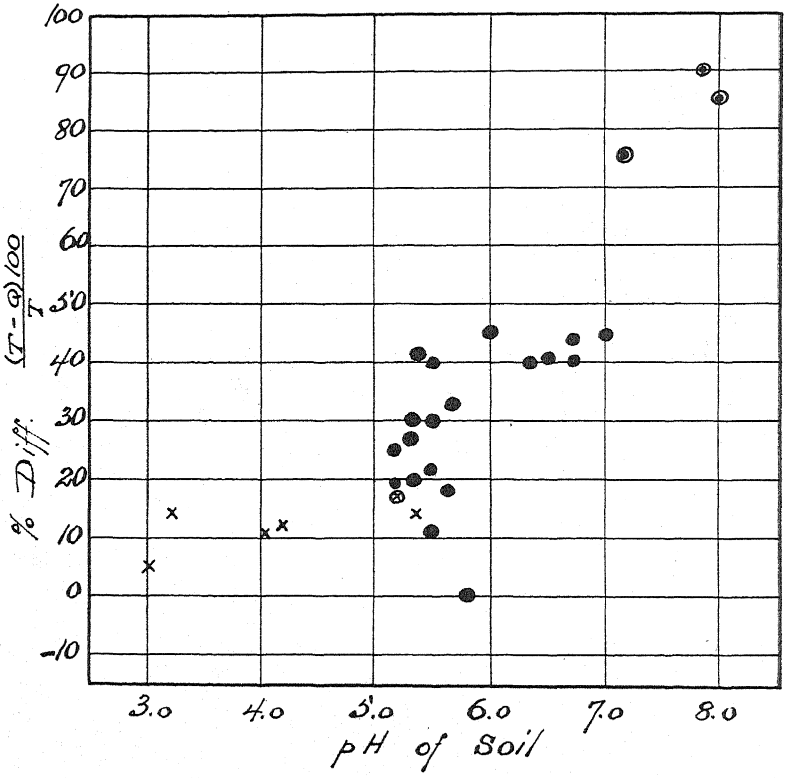

FIG. 2.—The relation of the percentage difference between Truog and Quebec extraction of phosphate and the reaction of inorganic soils. ● brown forest soil; x podsol. Encircling indicates subsoil.

In Fig. 2 the percentage difference between results is plotted against the pH of the soil for the soils of inorganic nature, that is, the brown forest soil and podsol samples.

Considering the data presented in Table 3, it is evident that the results of the two methods are closely related, showing covariance throughout. However, a fairly consistent difference is also evident. In general, the Quebec solution, containing calcium, extracts less phosphate than the Truog solution. This is especially true for the inorganic soils. From a practical standpoint, the actual differences between the results of the two methods are of apparent significant magnitude in relatively few cases.

The information presented in Fig. 2 gives a fairly definite indication that the percentage difference between the results of the two methods tends to be a function of the reaction of the soil. The percentage differences tend to be small for very acid soils and to increase markedly for soils of higher pH values. It may be that this is because reaction is associated with calcium content in these soils.

Inspection of the percentage differences obtained for unfertilized and fertilized muck soils fails to reveal a similar well-defined relation to soil pH value. The percentage differences appear to be widely variable, and the Quebec solution extracts as much as or more phosphorus than the Truog in about half the cases, notably the subsoil samples. Actual differences in the results obtained on these soils would scarcely influence their characterization as regards available phosphorus. It should be pointed out, however, that the Truog extracts of these soils were discolored, in some cases sufficiently so to make the colorimetric determination very difficult and uncertain, whereas the Quebec method extraction gave water-clear to faintly tinted extracts. This points to another important difference in the action of calcium and ammonium ions, probably on the organic matter. For muck soils, in this respect, the Quebec solution is superior from a practical standpoint.

Comparing the extraction of inorganic soils by comparably acid solutions containing ammonium and calcium ions, respectively, it appears that the calcium-containing solution tends to extract less phosphorus, and that the percentage differences increase with increasing pH values of the soils. Significant actual differences between the amounts extracted are rare for acid soils but rather prevalent in the case of neutral and calcareous soils. Thus, the extraction with the Quebec solution containing calcium and sulfate ions, which is perhaps more closely related to natural soil conditions, may provide a truer estimate of the phosphate in the soil which is actually available to plants. It is hoped that further investigation may provide information concerning this matter.

SUMMARY

Differences in the extracting powers of comparable solutions of $KHSO_4$ and $Ca(HSO_4)_2$ and of comparable solutions containing $(NH_4)_2SO_4$ and $CaSO_4$, have been demonstrated. The cations present affect the solubility of soil phosphates.

The drastic action of solutions at pH 2.0 has been shown.

The dependence of the difference in the extracting power of acid $(NH_4)_2SO_4$ and acid $CaSO_4$ solutions upon soil pH values or associated properties has been indicated.

The probable advantages of extraction with a solution containing calcium and sulfate ions have been pointed out.

LITERATURE CITED

1. DAS, S. An improved method for the determination of available phosphoric acid in soils. Soil Science, 30 : 33–48. 1930.
2. DENIGES, G. Reaction de coloration extremement sensible des phosphates et des arseniates. Ses applications. Compt. rend. de l'Acad. de Science de Paris, 171 : 802. 1920.
3. HANDBOOK OF CHEMISTRY AND PHYSICS. Cleveland: Chemical Rubber Publishing Co. Ed. 16. 1930.
4. LOHSE, W. H., and RUHNKE, G. N. Studies on readily soluble phosphate in soils: I. Extraction of readily soluble phosphate from soils by means of dilute acid potassium sulphate ($KHSO_4$). Soil Science, 35 : 437–457. 1933.
5. MCGEORGE, W. T., and BREAZEALE, J. F. Phosphate solubility studies on some unproductive calcareous soils. Ariz. Agr. Exp. Sta. Tech. Bul. No. 35. 1931.
6. NEUBAUER, H., and SCHNEIDER, W. Die Nahrstoffaufnahme der Keimpflanzen und ihre Anwendung auf die Bestimmung des Nahrstoffgehalts der Boden. S. f. Pflanz., Dung. u. Bodenk. A : 329–341. 1923.
7. THORNTON, S. F. The available phosphorus and potassium contents of surface soils and subsoils as shown by the Neubauer method and by chemical tests. Jour. Amer., Soc. Agron., 27 : 46–51. 1935.
8. TRUOG, E. The determination of readily available phosphorus of soils. Jour. Amer. Soc. Agron., 22 : 874–882. 1930.
9. TRUOG, E., and MEYER, A. H. Improvements in the Deniges colorimetric method for phosphorus and arsenic. Ind. and Eng. Chem., Anal. Ed., I : 136–139. 1929.

A COMPARISON OF GLASS AND QUINHYDRONE ELECTRODES FOR DETERMINING THE pH OF SOME IOWA SOILS: II. THE VARIABILITY OF RESULTS[1]

Harold L. Dean and R. H. Walker[2]

In the first paper of this series (1)[3], results were presented of experiments conducted to determine the suitability of different types of glass electrodes for measuring the pH of soils. It was found that similar results were obtained with each of the four types of glass electrodes studied, and that the variability in pH of replicate samples of soil was extremely small with each type of glass electrode. The modified bulb, silver-silver chloride type of glass electrode, however, was found most practicable and desirable because of its ease of construction, strength, durability, and also because of the simplicity of keeping it in proper condition for use. Several glass electrodes of the modified bulb type constructed from one stock of glass were found, in the main, to function similarly, and the data indicated that these electrodes may be depended upon to give accurate results.

The next problem in the comparison of glass and quinhydrone electrodes was to determine the normal variation of results of pH determinations made by the two methods. It seemed desirable also to determine, for the soils under observation, the nature and magnitude of the "QH error" and the "QH electrode error" by means of the glass electrode. The data obtained in these studies are presented in this paper.

EXPERIMENTAL PROCEDURE

The modified bulb, silver-silver chloride type of glass electrode, and the ordinary type of platinum electrode with quinhydrone were employed in making the pH determinations in this study. A vacuum tube amplifying unit, constructed according to Goodhue and described in the first paper of this series (1), was used in making the measurements. The voltage readings given by the electrodes were calculated to pH by the Youden and Dobroscky (4) method.

In the study five types of soil were employed, namely, Tama silt loam, Grundy silt loam, Shelby loam, Marshall silt loam, and Carrington loam. A 30.0-gram sample of soil was placed in a 150-cc extraction flask and mixed with 75 cc of CO_2-free distilled water. The mixture was shaken for 1 minute, allowed to stand for 2 hours, and then the supernatant liquid was poured into a specially constructed U-shaped tube and the glass electrode introduced into the liquid. The electrode was so adjusted that the surface of the liquid inside the electrode was level with the surface of the liquid outside. The KCl-agar bridge making contact with the calomel half-cell was then introduced into the liquid and the potential determined. After the pH of the supernatant liquid was determined with the glass

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[3] Figures in parenthesis refer to "Literature Cited," p 525.

electrode, 0.2 to 0.4 gram of quinhydrone was added and shaken for 15 seconds after which the pH was determined with the quinhydrone electrode.

VARIABILITY OF RESULTS

In order to determine the normal variation of the results obtained by the quinhydrone and glass electrodes, determinations were made on 25 samples of each of the five soils studied, these samples being taken from a large uniform sample of each soil which had been screened and thoroughly mixed. The results obtained are shown in Table 1. A statistical analysis of the results showing the range of variation and the standard deviation is shown in Table 2.

TABLE 1.—*The pH of 25 samples of each of five soils determined by the glass and quinhydrone electrodes.*

No.	Carrington loam		Tama silt loam		Marshall silt loam		Grundy silt loam		Shelby loam	
	Glass	Quin.	Glass	Quin.	Glass	Quin.	Glass	Quin.	Glass	Quin.
1	5.18	5.23	4.98	4.94	—	—	5.40	5.47	5.92	5.99
2	5.16	5.25	4.96	4.98	—	—	5.37	5.45	5.91	5.94
3	5.18	5.25	4.94	5.06	7.55	7.26	5.35	5.50	5.89	5.92
4	5.18	5.23	4.93	5.03	7.55	7.40	5.35	5.48	5.87	5.97
5	5.20	5.23	4.98	5.06	7.43	7.12	5.33	5.45	5.87	5.96
6	5.20	5.23	4.96	5.03	7.41	7.34	5.33	5.45	5.91	5.94
7	5.15	5.23	4.94	4.99	7.43	7.16	5.35	5.45	5.87	5.96
8	5.13	5.25	4.96	5.03	7.46	7.24	5.43	5.42	5.82	5.96
9	5.06	5.23	4.96	5.03	7.43	7.18	5.37	5.40	5.82	5.94
10	5.18	5.23	4.96	5.04	7.45	7.14	5.35	5.40	5.87	5.92
11	5.06	5.21	4.99	5.06	7.45	7.29	5.35	5.43	5.91	5.94
12	5.08	5.20	4.96	4.94	7.45	7.26	5.33	5.43	5.84	5.89
13	5.08	5.21	4.98	5.03	7.45	7.07	5.35	5.45	5.82	5.91
14	5.08	5.20	4.98	5.01	7.45	7.07	5.35	5.43	5.82	5.87
15	5.03	5.21	4.96	5.03	7.41	7.18	5.37	5.48	5.82	5.89
16	5.09	5.21	4.98	5.04	7.41	7.14	5.38	5.47	5.86	5.92
17	5.09	5.23	4.98	5.03	7.33	7.11	5.37	5.47	5.84	5.96
18	5.06	5.16	4.98	5.04	7.40	7.18	5.35	5.48	5.81	5.89
19	5.11	5.23	4.96	5.03	7.40	7.26	5.35	5.47	5.82	5.94
20	5.11	5.18	4.96	5.04	7.43	7.21	5.35	5.45	5.75	5.96
21	5.09	5.23	4.98	5.03	7.33	7.23	5.37	5.47	5.77	5.81
22	5.13	5.23	4.94	5.04	7.48	7.21	5.31	5.43	5.79	5.89
23	5.09	5.21	4.94	5.03	7.45	7.04	5.37	5.45	5.77	5.89
24	5.09	5.11	4.96	5.03	7.46	7.14	5.35	5.45	5.82	5.89
25	5.09	5.18	4.98	5.04	7.50	7.16	5.33	5.47	5.84	5.92
Mean	5.12	5.21	4.96	5.02	7.44	7.19	5.36	5.45	5.84	5.92

It is evident from the data that some variation between samples occurred, but the total range of variation in pH, determined by the glass electrode, was within 0.06 pH for the 25 samples of Tama silt loam. It is also shown by the standard deviation that two-thirds of the determinations on this soil gave results which varied within 0.017 pH above or below the mean. The data secured with other soils varied

TABLE 2.—*Statistical analysis of the variations in the pH of 25 samples of each of five soils.*

Soil type	Glass electrode			Quinhydrone electrode		
	Mean pH	Range	Standard deviation	Mean pH	Range	Standard deviation
Tama silt loam.........	4.96	0.06	0.017	5.02	0.12	0.031
Carrington loam........	5.12	0.17	0.051	5.21	0.14	0.031
Grundy silt loam.......	5.36	0.12	0.022	5.45	0.10	0.035
Shelby loam...........	5.84	0.17	0.046	5.92	0.18	0.039
Marshall silt loam......	7.44	0.22	0.047	7.20	0.36	0.089

slightly more than this and were most variable in the case of the Marshall silt loam, where the range of variation was 0.22 pH. Even with this soil, however, the standard deviation was not large, being only 0.047 pH.

The mean pH values obtained with the quinhydrone electrode were somewhat higher with most soils than those obtained with the glass electrode. The significance of this point will be discussed later. The total range of variation of the results obtained with the quinhydrone electrode for Tama silt loam was within 0.12 pH, and two-thirds of the results varied within 0.031 pH above or below the mean as indicated by the standard deviation. As was the case with the glass electrode, the data obtained with other soils varied slightly more than this. The Marshall silt loam gave the most variable results, the range of variation being 0.36 pH and the standard deviation being 0.089 pH.

It appears that the variability of the results obtained with the glass and quinhydrone electrodes is only slightly different for the various acid soils. In the case of the basic Marshall silt loam, however, there was somewhat less variability in the results obtained with the glass than with the quinhydrone electrode. It would seem, therefore, that the glass electrode is as reliable as the quinhydrone electrode for determining the pH value of soils.

THE "QH" AND "QH ELECTRODE" ERRORS

In the next experiment, in which the "QH error" and the "QH electrode error" were determined, the soils were prepared for analysis in the same manner as in the previous experiment. The pH determinations were made on the soil suspension in this case, however, instead of on the supernatant liquid. A glass and a quinhydrone electrode were each fitted into a rubber stopper so that determinations could be made by either electrode at any time. The measurements were made at intervals of 0.5, 2.0, 5.0, 10.0, and 20.0 minutes.

The "QH error" has been defined by Naftel (2) as the difference between the pH value of the soil suspension when determined by the glass electrode and the pH value of a suspension of the same soil when determined in the same way after the addition of quinhydrone. The "QH electrode error" is defined as the difference in the pH value determined by the glass electrode after adding quinhydrone and the pH value of the same soil suspension determined by the quinhydrone electrode at the same time.

The "QH" and "QH electrode" errors obtained from this study are shown in Table 3. In making the determinations it was found that where the glass electrode was used without quinhydrone in the soil suspensions the pH readings varied somewhat at different intervals of time. There was little or no change in the pH of the Tama soil, a slight increase in the pH of the Shelby soil, and a slight decrease in the pH of the Carrington, Grundy, and Marshall soils. The maximum change occurred in the Marshall silt loam where the pH decreased 0.17 in 20 minutes. The largest change in pH occurred, in all cases, during the first 2 minutes after immersion of the electrode in the soil suspension.

TABLE 3.—*The "QH error" and the "QH electrode error" in the pH determinations on five soils.*

Time in min.	Tama silt loam		Carrington loam		Shelby loam		Grundy silt loam		Marshall silt loam	
	"QH"	"QH E"	"QH"	"QH E"	"QH"	"QH E"	"QH"	"QH E"	"QH"	"QH E"
	0.2 gram Quinhydrone Added									
0.5	+0.07	−0.04	+0.12	+0.06	+0.26	+0.01	+0.07	+0.03	+0.06	−0.13
2.0	+0.09	−0.01	+0.17	0.00	+0.21	−0.01	+0.11	−0.06	+0.09	−0.15
5.0	+0.12	−0.05	+0.22	−0.03	+0.23	−0.07	+0.03	+0.03	+0.07	−0.11
10.0	+0.14	−0.05	+0.19	−0.03	+0.22	−0.08	+0.08	−0.01	+0.08	−0.06
20.0	+0.17	−0.07	+0.21	−0.04	+0.10	−0.01	+0.08	−0.01	−0.06	+0.03
	0.45 gram Quinhydrone Added									
0.5	+0.16	−0.02	+0.11	+0.05	+0.27	+0.01	+0.13	+0.04	+0.01	−0.09
2.0	+0.14	+0.01	+0.19	+0.02	+0.24	0.00	+0.09	+0.03	+0.06	−0.10
5.0	+0.11	0.00	+0.16	+0.02	+0.21	+0.02	+0.06	+0.01	+0.02	−0.07
10.0	+0.13	0.00	+0.16	+0.01	+0.21	−0.04	+0.09	−0.03	+0.01	−0.01
20.0	+0.15	−0.01	+0.19	+0.03	+0.14	−0.02	+0.07	−0.01	−0.05	+0.03
	0.90 gram Quinhydrone Added									
0.5	+0.13	0.00	+0.18	−0.01	+0.31	−0.04	+0.12	+0.03	0.00	−0.09
2.0	+0.13	0.00	+0.24	−0.02	+0.23	0.00	+0.13	−0.08	+0.05	−0.09
5.0	+0.15	−0.07	+0.17	+0.03	+0.20	0.00	+0.12	−0.10	+0.03	−0.07
10.0	+0.15	−0.06	+0.16	−0.01	+0.17	+0.01	+0.11	−0.06	+0.06	−0.06
20.0	+0.16	−0.04	+0.20	−0.01	+0.13	−0.01	+0.09	−0.07	0.00	−0.02

It was also found that the addition of quinhydrone to the soil suspension increased the pH when determined by the glass electrode. The change in pH varied from 0.06 to 0.26 for the different soils, the smallest change occurring in the Marshall silt loam and the largest change in the Shelby loam. There seemed to be little or no difference in the amount of change exerted by the different amounts of quinhydrone employed in this experiment. Apparently the smallest amount added, 0.2 gram, was sufficient to bring about the maximum change. The most rapid change in pH occurred immediately after the quinhydrone was added to the soil suspension. During the next 20 minutes there was also some change in the pH of the soil suspension, but this change was presumably of little consequence as compared with the initial change induced upon the addition of the quinhydrone.

Similar results were obtained when the quinhydrone electrode was employed. There was an increase in the pH values of the soil suspensions after the addition of the quinhydrone when determined by the quinhydrone electrode and compared with the original pH determinations made on the soil suspensions with the glass electrode in the absence of quinhydrone. It is concluded, therefore, that the addition of quinhydrone to these soils changed to a slight extent the observed potentials obtained with the glass and quinhydrone electrodes. These conclusions are in agreement with those of Naftel (2), and Naftel, Schollenberger, and Bradfield (3).

Appreciable amounts of manganese dioxide in soils are known to change the pH in the presence of quinhydrone. It is possible that the soils studied here contained sufficient amounts of this compound to produce the changes observed, but apparently the amounts were not excessive as in the case of certain soils reported by Naftel (2). These soils may, therefore, be grouped with those of Naftel giving fair results with the quinhydrone electrode, and it is concluded that the quinhydrone electrode may be used to determine the pH of these and similar soils without serious error.

Certain investigators have attributed the erroneous results obtained by the quinhydrone electrode method to the improper functioning of the electrode itself. In order to determine whether or not this is the case an additional measurement of the pH of the soil suspensions containing quinhydrone was made with the quinhydrone electrode immediately after the pH was determined with the glass electrode. As was stated above, the difference in the pH readings obtained by these two electrodes is considered as the "QH electrode error". The results obtained in these tests are shown in Table 3. It is obvious that there was very little difference in the results obtained with the glass and quinhydrone electrodes under these conditions, and that the "QH electrode error", determined in this manner, is very little if any larger than the normal variation that may be expected with replicate determinations. Hence, it would seem that the "QH electrode error" for these soils is of little or no consequence. This is in agreement with Naftel's conclusions (2).

CHANGES IN ELECTRODE POTENTIALS

In these and other experiments it was observed that the pH, when determined by either the glass or quinhydrone electrodes, changed somewhat with time. This change has frequently been referred to as a drift in potential. There has been some question whether or not this drift is due to an actual change in the hydrogen-ion concentration of the soil or to a change in the potentials of the electrode used. It was considered desirable, therefore, to check the potentials of the electrodes in a potassium acid phthalate buffer solution of pH 3.97 before and after the electrodes were suspended in a soil solution for 20 minutes. The results of this study are given in Table 4. It may be observed that the potential of the glass electrode changed somewhat during the 20 minutes the electrode was in contact with the soil suspensions. These changes varied from 0.001 to 0.0036 millivolt for the various soils and under the different conditions studied. The average

TABLE 4.—*Glass and quinhydrone electrode potentials in millivolts before and after immersion in soil suspensions for 20 minutes.*

Soil type	QH added, grams														
	None			0.1			0.2			0.45			0.90		
	Before	After	Diff.	Before	After	Diff.	Before	After	Diff.	Before	After	Diff.	Before	After	Diff.
							Glass Electrode								
Carrington	0.1488	0.1491	0.0003	0.1474	0.1451	0.0023	0.1510	0.1516	0.0006	0.1469	0.1457	0.0012	0.1439	0.1443	0.0004
Grundy	0.1499	0.1500	0.0001	0.1517	0.1482	0.0035	0.1488	0.1476	0.0012	0.1469	0.1478	0.0009	0.1492	0.1486	0.0006
Tama	0.1559	0.1523	0.0036	0.1499	0.1490	0.0009	0.1521	0.1511	0.0010	0.1485	0.1504	0.0019	0.1490	0.1489	0.0001
Shelby	0.1490	0.1482	0.0008	0.1534	0.1511	0.0023	0.1509	0.1489	0.0020	0.1490	0.1457	0.0033	0.1479	0.1452	0.0027
Marshall	0.1249	0.1253	0.0004	0.1201	0.1179	0.0022	0.1205	0.1190	0.0015	0.1209	0.1208	0.0001	0.1204	0.1201	0.0003
							Quinhydrone Electrode								
Carrington	—	—	—	0.2162	0.2158	0.0004	0.2168	0.2169	0.0001	0.2165	0.2165	0.0000	0.2160	0.2159	0.0001
Grundy	—	—	—	0.2189	0.2185	0.0004	0.2197	0.2198	0.0001	0.2181	0.2179	0.0002	0.2176	0.2173	0.0003
Tama	—	—	—	0.2201	0.2199	0.0002	0.2212	0.2188	0.0024	0.2182	0.2181	0.0001	0.2189	0.2181	0.0008
Shelby	—	—	—	0.2168	0.2174	0.0006	0.2169	0.2161	0.0008	0.2176	0.2179	0.0003	0.2178	0.2176	0.0002
Marshall	—	—	—	0.2131	0.2129	0.0002	0.2133	0.2135	0.0002	0.2131	0.2130	0.0001	0.2133	0.2130	0.0003

change in potential of the quinhydrone electrode was somewhat smaller than that for the glass electrode, the largest change being 0.0024 millivolt. It may be of interest to note that 0.0059 millivolt is necessary to make a change of 0.1 pH.

Although the changes in the potentials of the glass electrode, when checked against a standard buffer solution before and after use, were comparatively small, it was considered a desirable precautionary measure to check the potentials of this electrode at frequent intervals while it is being employed for determining the pH of soils. It may also be desirable to check the potentials of the quinhydrone electrode in the same manner, but apparently this is not so important with the quinhydrone electrode as it is with the glass electrode.

SUMMARY AND CONCLUSIONS

1. The variability of the results obtained by the use of the glass and quinhydrone electrodes for determining the pH of some Iowa soils was studied, and the nature and magnitude of the "QH error" and the "QH electrode error" were determined by means of the glass electrode. The potentials of the glass and quinhydrone electrodes were checked in a potassium acid phthalate buffer solution before and after the electrodes were suspended in a soil suspension for 20 minutes.
2. The variability in the pH of 25 samples of different soils, when determined by either the glass or the quinhydrone electrode, was comparatively small and presumably of little practical consequence.
3. The addition of quinhydrone to the soil suspension increased the pH of each soil slightly when determined by the glass or quinhydrone electrodes. This change in pH resulting from the addition of quinhydrone to the soil is referred to as the "QH error". This error was scarcely large enough to make the quinhydrone electrode method unreliable for determining the pH of the soils studied.
4. The glass and quinhydrone electrodes gave similar results when employed to determine the pH of soil suspensions containing quinhydrone. The "QH electrode error", therefore, is of little or no consequence in the soils studied.
5. The potentials of the glass and quinhydrone electrodes change somewhat during the process of pH determinations. It is desirable. therefore, to check these electrodes against a known buffer solution at frequent intervals.

LITERATURE CITED

1. Dean, Harold L., and Walker, R. H. A comparison of glass and quinhydrone electrodes for determining the pH of some Iowa soils: I. A comparison of different types of glass electrodes. Jour. Amer. Soc. Agron., 27 : 429–436. 1935.
2. Naftel, James A. The glass electrode and its application in soil acidity determinations. Soil Res., 4 : 41–50. 1934.
3. ——————, Schollenberger, C. J., and Bradfield, Richard. A study of the methods for determining soil reaction using the glass electrode. Soil Res., 3 : 222–246. 1933.
4. Youden, W. G., and Dobroscky, J. D. A capillary glass electrode. Cont. Boyce-Thompson Inst. Plant Res., 3 : 347–362. 1931.

THE COMPARATIVE ROOT DEVELOPMENT OF REGIONAL TYPES OF CORN[1]

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THE root systems of regional types of corn (*Zea Mays* L.) differing materially aboveground were studied to discover any inherent morphological differences. Investigations during the last four decades by Hays (1),[3] Ten Eyck (6), and Weaver (8) have added much to our general knowledge of the root system of corn but did not concern the comparative development of divergent vegetative types. In other species definite differences in root systems have been shown by Mohammad and Deshpande (5) with chillies, by Venkatraman and Vittal (7) with sugar cane seedlings, and by Jean (2) with peas. This suggests their possible existence among divergent types of corn.

Accordingly, varieties differing materially in mature plant height, number and area of leaves, earliness of maturity, etc., when grown at Lincoln, Nebr., were assembled from various regions. A natural classification grouped the varieties representative of corn adapted to northern, central, and southern areas of the United States into small, medium, and large vegetative types, respectively. The gross morphology of the root systems was studied under normal field conditions, while root weight and volume were determined under pot culture.

EXPERIMENTAL PROCEDURE

GROWTH CONDITIONS AND SEED SOURCES

The various types were grown comparably at Lincoln in 1933 under the same environmental conditions in order that any stalk and root differences between them might be attributed to heritable behavior. The soil was Carrington silt loam which is typical of extensive areas in which corn is grown. Plant development was rather normal as indicated by a grain yield of 43 bushels per acre from the Krug variety grown in this experiment as compared with a 33-year average of 46 bushels for standard varieties on the Experiment Station farm.

The small varieties, Rustler from North Dakota and Minnesota 13 from western Nebraska; the medium large varieties, Krug from southeastern Nebraska, Pride of Saline from Kansas, and Hulsart Yellow Dent from New Jersey; and the large varieties, Reese Drought Resister from Texas and Mexican June from Arizona, were, respectively, characteristic of corn grown in northern, central, and southern areas of the United States. All varieties were dent corn well adapted to the regions from which they came.

CULTURAL METHODS

Hays (1), Ten Eyck (6), and Weaver (8) have found the maximum spread of the main roots of corn to be approximately 3.5 feet in all directions from the

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[2] Assistant in Agronomy. The writer is indebted to Dr. T. A. Kiesselbach, Agronomist, Nebraska Agricultural Experiment Station, for many contributions of helpful information.

[3] Figures in parenthesis refer to "Literature Cited," p. 537.

stalk. Accordingly, competition, which might modify normal heritable root behavior, was largely eliminated in these experiments by growing the plants singly in hills spaced 7 feet apart. The field was tilled with a sweep cultivator deep enough to destroy the weeds without injuring the main roots of the corn. All tillers were carefully removed at an early stage in order to eliminate this variable factor.

To facilitate determinations of the volume and the weight of roots, one representative variety of each type was grown to maturity in triplicated pots 16 x 36 inches in size. The pots were filled with fertile Carrington silt loam soil which had been screened to remove organic debris. Water and fertilizers were applied in sufficient quantities to permit normal aerial development. Any moisture draining from the pots was collected and returned to the one from which it percolated. One plant was grown per pot.

ROOT EXAMINATIONS

The main roots of the secondary root system of plants grown in the field were studied periodically from the seedling to the mature stage. These roots in contrast to those of the primary system increase in number after the seedling stage, as shown in Fig. 1, and in dent corn are ultimately 15 to 20 times as numerous. Although the primary root system may live to maturity and penetrate 5 to 6 feet deep, it was frequently dead on many normal-appearing plants shortly after the appearance of the secondary root system. A study of the primary root system was not included in these investigations because its number of main roots is constant after the seedling stage and because it comprises such a small part of the entire number of roots of older plants that variations within it would seem to have little importance.

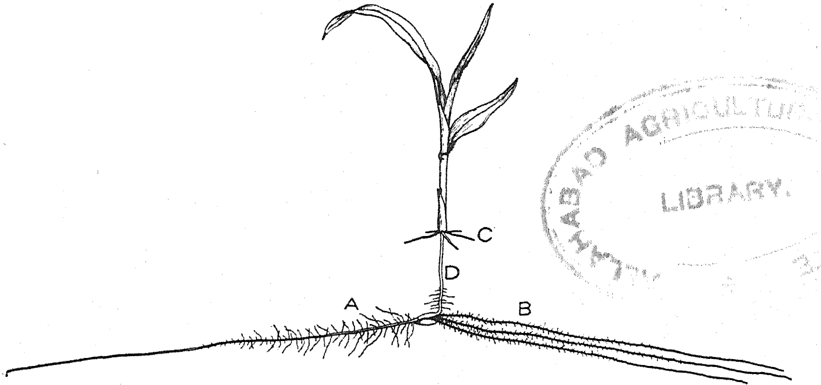

FIG. 1.—The primary and secondary root systems of a representative corn plant with three expanded leaves. A and B, the primary and seminal roots, respectively, of the primary root system. C, initial whorl of roots of the secondary root system. Approximately 80 additional roots are formed later from the next eight higher nodes of corn suitable to southeastern Nebraska. D, epicotyl.

The roots of a representative plant of each variety were examined 2, 4, 6, 8, and 12 weeks after planting. The small varieties were mature at the end of the twelfth week. Subsequently, an additional examination was made of the larger varieties as they matured. The root determinations were accomplished in the main according to technic described by Weaver (8). A trench was dug along one side of the plant. The roots were exposed, singly, by the use of a shovel, pick, and ice pick. After obtaining the desired data, each root was removed to facilitate the tracing of others. All of the main roots were traced for plants excavated 2 and 4 weeks after planting. Thereafter, only half of them, or those located on one side of a median line through the plant, were examined. Fig. 2 shows a few roots of a mature plant partially uncovered.

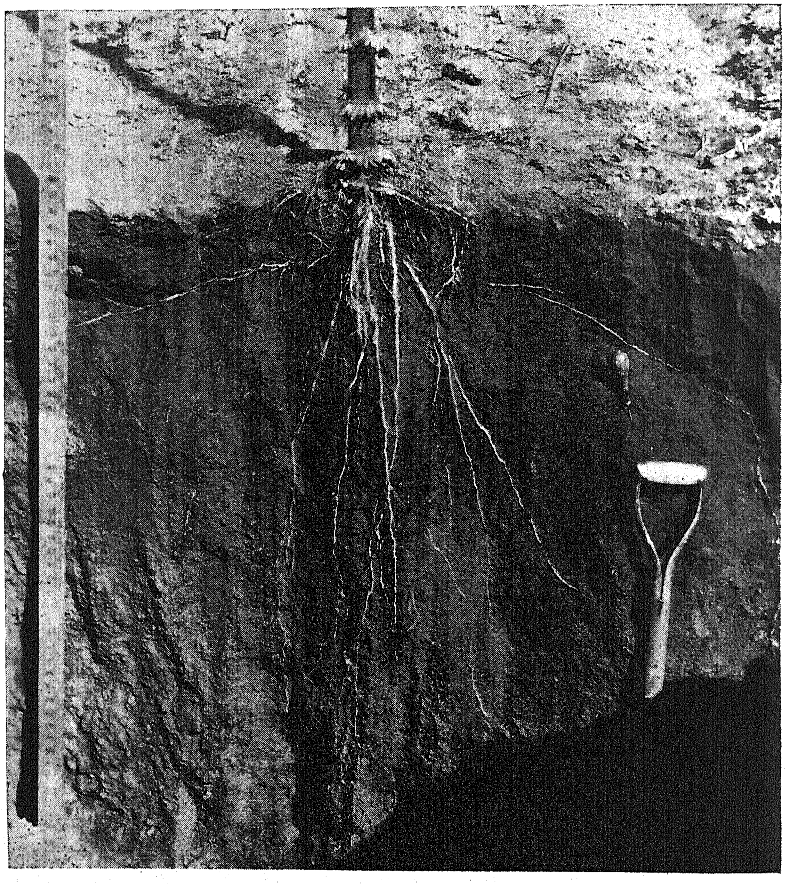

FIG. 2.—A mature plant of the variety Mexican June with its root system partially uncovered.

For the plants grown in pots, the soil was slowly washed from the roots at maturity. Any loose root fragments were caught in a screen through which all drainage water passed. Fig. 3 shows a root system after about half of the soil had been removed. Root volumes by the water displacement method and moisture-free weights were obtained.

PRESENTATION OF DATA

The varieties used in this study were selected to represent small, medium, and large types. Examination of the data for aboveground characters of mature plants substantiated this grouping. As it was not the purpose to study specific varieties, only the mean data for each type are presented.

DIFFERENCES BETWEEN TYPES AT MATURITY

STALK CHARACTERS

The data in Table 1 show that three distinct types of corn differing in vegetative size, as desired, were grown. Comparing the small, medium, and large types, the respective values for various plant characters were as follows: (a) Number of days from planting to tasseling 50, 65, and 79; (b) number of days from planting to ripening 88, 112, and 129; (c) stalk height 55, 87, and 92 inches; (d) number of leaves from nodes aboveground 12, 17, and 20; (e) leaf area 658, 1,412, and 1,747 square inches; (f) stalk diameter 22, 27, and 32 mm; (g) moisture-free fodder weights per plant 248, 380, and 622 grams; and (h) acre yield of stover 1,766, 3,628, and 4,458 pounds. The grain yield was greatest for the medium type as was to be expected for varieties most nearly adapted at Lincoln.

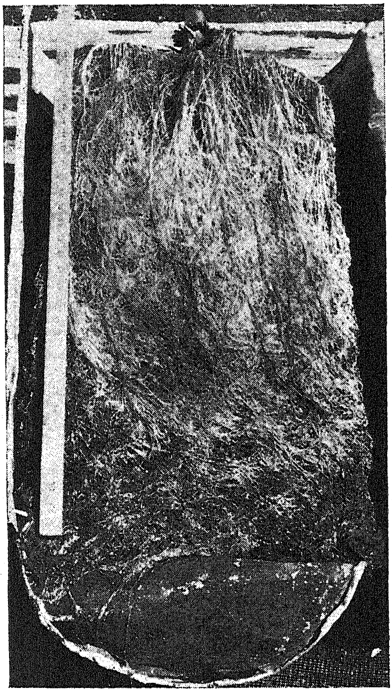

FIG. 3.—The root system of a mature plant of the Krug variety grown in a pot (16 x 36 inches.) Approximately one-half of the roots have been exposed by washing.

The number of root-bearing nodes, as well as the total number of nodes per stalk increased with varietal size (Table 1). The lowest 8, 12, and 14 stalk nodes of the small, medium, and large types, respectively, bore roots. Of these, the 7, 8, and 9 nodes occurring belowground and usually the first one aboveground in the respective types bore functional roots. The roots from higher nodes were non-functional and failed to reach the soil.

The various types were rather similar in regard to the percentage of stalk nodes with roots. These percentages were, respectively, 42, 48, and 48.

SPREAD OF SECONDARY ROOT SYSTEM

The spread of roots is expressed in two ways in this paper, *viz.*, (a) the *maximum spread* of any main root from the base of the plant, and

(b) the *average spread* of main roots arising from that node whose roots attain the greatest average distance from the stalk. In general, both the maximum and average spread tended to increase with varietal size. The maximum spread was 36, 48, and 54 inches (Table 2) for the small, medium, and large varieties, respectively, whereas the average spread for the respective types was 35, 39, and 38 inches. The corresponding relative values for maximum spread were 100, 133, and 150% compared with 100, 111, and 109% for the average spread.

TABLE 1.—*The comparative stalk development at maturity and the number of days from planting to tasseling and to ripening of the small, medium, and large corn types.*

Characters observed	Varietal type		
	Small	Medium	Large
Number of varieties averaged	2	3	2
Individual plant data:			
Days from planting to tasseling	50	65	79
Days from planting to ripening	88	112	129
Height to first tassel branch, in.	55	87	92
Leaf area sq. in.	658	1,412	1,747
Stalk diameter at base, mm.	22	27	32
Moisture-free fodder weight, grams	248	380	622
Nodes:			
Total number	19	25	29
Bearing roots	8	12	14
Relative no. bearing roots, %	42	48	48
Above ground with leaves	12	17	20
Above ground with roots	1	4	5
Below ground with roots	7	8	9
With functional roots	8	9	10
With functional aerial roots	1	1	1
With non-functional aerial roots	0	3	4
Acre yield:			
Stover, lbs.	1,766	3,628	4,458
Grain, bu.	23	37	19

The spread of approximately one-fourth of all the roots of each regional type exceeded 1.5 feet, whereas it was less than this amount for the remaining three-fourths of the roots. This suggests that the widely spreading 25% of the roots of individual plants occupied 3 times as large a soil volume as the nearly vertical 75%. The widely spreading roots arose from the lowest three, four, and five nodes of the small, medium, and large varieties, respectively, while the nearly vertical roots grew from the next five higher nodes of each type. These principles are depicted in Fig. 4 which is a graphic presentation of the secondary root systems of the three types.

In general, the spread was greatest for the roots from the lower stalk nodes and decreased as nodal position on the stalk became higher. For the small, medium, and large types the mean spread of roots from the lowest stalk node (Tables 2 and 3) was, respectively, 35, 35, and 34 inches, but from the highest node with functional roots only 7, 6, and 5 inches.

TABLE 2.—*The comparative development of the secondary root system of the small, medium, and large corn types at maturity.**

Characters observed	Varietal type		
	Small	Medium	Large
Number of varieties averaged	2	3	2
Lateral spread of roots:			
Maximum, in	36	48	54
Average for node† with greatest root spread, in	35	39	38
Av. for lowest stalk node, in	35	35	34
Av. for highest node with functional roots, in.	7	6	5
Depth of root penetration:			
Maximum, in	67	73	74
Average, in	47	54	58
Functional roots	60	85	99
Non-functional aerial roots	3	47	81
Combined length of main roots, ft	283	346	545
Combined length‡ of main roots and branches, miles	5	6	9
Branches per inch of main root**	11	12	10
Root diameter, mm.**	1.5	1.7	2.1
Root volume, cc.††	403	749	1,484
Root weight, grams††	36	77	148
Dry weight‡ of roots per acre, lbs	445	1,080	1,420

*All data are for plants grown in the field except volume and weight which were determined from plants grown in pots.

†This node was the 1st, 2nd, and 2nd in the small, medium, and large types, respectively.

‡Estimated.

**Average of the measurements near the base, midpoint, and tip of roots.

††One variety of each type was grown in triplicate pots.

DEPTH OF ROOT PENETRATION

The deepest penetrating roots at maturity were usually observed in the larger types. The maximum depth of penetration averaged 67, 73, and 74 inches (Table 2) for the small, medium, and large varieties, respectively, while the average depth of penetration for all main roots was 47, 54, and 58 inches for the corresponding varieties.

COMBINED LENGTH OF ROOTS

The combined length of all the main roots per plant at maturity (Table 2) was materially greater for the larger varieties. For the small, medium, and large types, respectively, these values were 283, 346, and 545 feet. It is estimated that the combined length of the branches was at least 90 times greater than that of the main roots. Accordingly, a plant of each of the respective types would possess about 5, 6, and 9 miles of roots (including branches).

NUMBER AND NODAL ORIGIN OF ROOTS

The larger varieties were found to have more functional and non-functional roots per plant. Functional roots arose from the underground nodes and usually the first node aboveground. The roots from higher nodes commonly desiccated before reaching the soil. The small, medium, and large types averaged 60, 85, and 99 functional roots per plant (Tables 2 and 3) which grew from the first 8, 9, and 10 nodes, respectively. Including the non-functional aerial roots from higher nodes the total number per plant for the respective types was 63, 132, and 180.

The larger varieties in contrast to the small had more root-bearing nodes per plant as well as a few nodes with higher numbers of roots. The 9th, 13th, and 17th were the uppermost nodes from which roots were observed to grow in the small, medium, and large varieties, respectively (Table 3). The number of roots per node increased rather progressively upwards from the lowest node, the maximum of 14.3, 20.1, and 22.0 roots occurring on the 7th, 9th, and 10th nodes, respectively, of the three types.

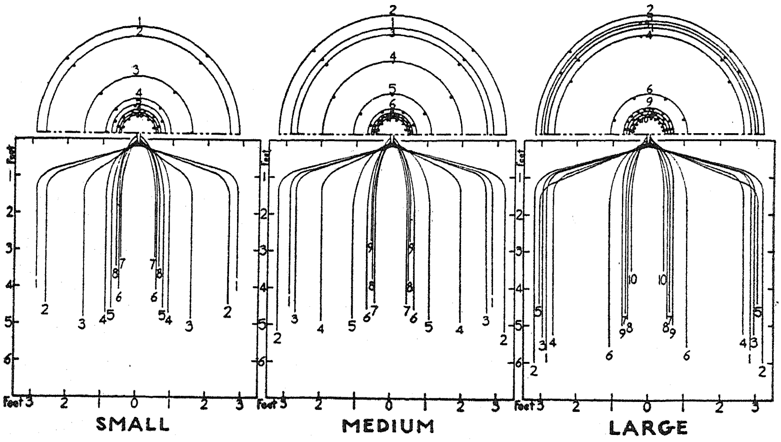

FIG. 4.—Diagrams of the secondary root systems (root branches are not shown) of the small, medium, and large types of corn at maturity. In the lower portion, the lines drawn from the base of the stalk show the average spread and depth of roots from individual nodes. Numbering upwards from the base of the stalk, the nodes from which the various roots arise are indicated by the numerals at the ends of the roots. The upper portion indicates the number and distribution of the roots on one side of the plant only. The radii of the various arcs correspond to the average spread of roots from the respective stalk nodes whose position is indicated by the numeral just above or on the arc. The number and approximate location of roots is shown for individual nodes by the small circles distributed systematically along the corresponding arcs.

NUMBER OF BRANCH ROOTS PER INCH OF MAIN ROOT

The data (Table 4) suggest that the largest varieties had a few less branches per inch of main root than either the small or the medium sorts. For all types, the number of branches near the base of the root was greatest for roots from higher stalk nodes. These numbers for roots from the two lowest and two highest stalk nodes were 15 and 26 per inch, respectively. The number of branches tended to decrease with distance from the base of the root. The averages for all nodes were 19 near the base, 9 near the midpoint, and 6 near the tip of the root.

TABLE 3.—*The average number and lateral spread of roots from successive stalk nodes of the small, medium, and large corn types at maturity.*

Stalk node	Mean lateral spread of roots from successive nodes, in.			Number of roots per node		
	Small	Medium	Large	Small	Medium	Large
1	34.5	34.5	34.2	4.4	4.2	4.5
2	31.3	38.7	38.3	4.2	4.1	4.6
3	18.6	32.3	35.6	4.0	4.4	4.7
4	10.8	23.7	32.0	5.2	5.6	5.8
5	7.4	12.0	36.0	7.3	7.1	6.6
6	6.4	8.0	13.1	11.0	9.3	8.4
7	6.0	5.7	7.3	14.3	13.1	11.6
8	6.8	6.0	6.9	11.2	16.8	15.8
9	—	6.4	8.5	1.6	20.1	19.0
10	—	—	5.4	—	19.6	22.0
11	—	—	—	—	16.8	21.9
12	—	—	—	—	7.9	19.8
13	—	—	—	—	2.6	17.2
14	—	—	—	—	—	9.8
15	—	—	—	—	—	5.2
16	—	—	—	—	—	2.3
17	—	—	—	—	—	0.5
Functional*	—	—	—	60.3	84.6	98.6
Non-functional	—	—	—	2.7	46.9	81.0
Total	—	—	—	63.0	131.5	179.6

*Functional main roots grew from the lowest 7.9, 8.0, and 9.8 stalk nodes of the small, medium, and large types, respectively. Roots from higher nodes commonly desiccated before reaching the soil.

DIAMETER OF MAIN ROOTS

The diameter of main roots of the medium and large types exceeded that for the corresponding nodes of the small type an average of 10 and 29%, respectively. The root diameter increased, progressively, from the lowest to the highest node. Near the base of the roots it averaged 1.2 mm for the two lowest nodes and 6.3 mm for the two highest nodes (Table 4). The diameter of the individual roots tended to decrease towards the tip. It averaged 1.2, 0.9, and 0.7 mm near the base, midpoint, and tip, respectively, of roots arising from the two lowest nodes, and 6.3, 1.2, and 0.8 mm for those originating in the two highest nodes.

VOLUME AND WEIGHT OF ROOTS

The aerial development at maturity of the small, medium, and large varieties grown in pots is compared in Table 5 with that of the corresponding regional types grown in the field. As it was rather similar for both types of culture, considerable credence is given to the root measurements.

The volume and weight of roots increased decidedly with varietal size. The root volume was 403, 749, and 1,484 cc (Table 5) for the small, medium, and large varieties, respectively, while the corresponding moisture-free weights were 36, 77, and 148 grams. The mois-

TABLE 4.—*The number of branches per inch of functional* main root and the diameter of functional main roots of the small, medium, and large corn types at maturity.*

Varietal type	Mean number of branches per inch of main root for nodes indicated			Mean diameter of main roots for nodes indicated, mm		
	2 lowest	2 highest	All nodes	2 lowest	2 highest	All nodes
			Near Base of Root			
Small	14.2	25.8	19.4	1.1	5.6	2.9
Medium	17.2	27.4	21.0	1.3	6.0	3.5
Large	13.1	23.9	17.5	1.2	7.2	4.1
Average	14.8	25.7	19.3	1.2	6.3	3.5
			At Mid-point of Root			
Small	7.4	10.7	9.2	0.8	0.9	0.9
Medium	10.3	12.6	10.6	0.9	1.3	1.1
Large	6.9	10.6	8.4	1.0	1.3	1.2
Average	8.2	11.3	9.4	0.9	1.2	1.1
			Near Tip of Root			
Small	5.7	6.3	5.9	0.7	0.7	0.7
Medium	5.8	6.0	5.9	0.6	0.8	0.6
Large	4.2	5.2	4.8	0.8	0.9	0.9
Average	5.2	5.8	5.5	0.7	0.8	0.7

*Refer to Table 3.

TABLE 5.—*The vegetative development of representative small (Rustler), medium (Krug), and large (Mexican June) corn varieties grown to maturity in pots.*

Type	Variety	In percentage of the respective types grown in the field			Root volume, cc	Moisture-free		Fodder weight ÷ root weight
		Plant height	Number of leaves	Moisture-free fodder		Root weight, grams	Fodder weight, grams	
Small	Rustler	103	95	93	403	36	231	6.42
Medium	Krug	91	93	99	749	77	377	4.90
Large	Mexican June	120	100	83	1,484	148	514	3.47
Average		105	96	92	—	—	—	—

ture-free fodder weights (including the base of the stalk) were 6.42, 4.90, and 3.47 times as heavy as the moisture-free root weights of the respective types. The acre yield of moisture-free fodder for plants spaced 21 inches in rows 42 inches apart was 2,870, 5,285, and 4,920 pounds for the small, medium, and large types, respectively. Dividing these yields by the corresponding fodder-root weight ratios, it may be calculated that the respective types added approximately 445, 1,080, and 1,420 pounds of dry root material per acre to the soil during the 1933 growing season. The computation for the medium varieties is corroborated by King (3) who estimated the amount to be 1,130 pounds and by Miller (4) whose calculation was 1,125 pounds.

TABLE 6.—*Vegetative development of the small, medium, and large corn types at progressive intervals after the planting date.*

Regional type	Aboveground parts				Secondary root system			
	Plant height, in.*	Leaf area, sq. in.	No. of leaves	Moisture-free fodder, grams	Av. depth of root penetration, in.	No. nodes bearing roots	Main roots: Combined length, feet	Main roots: No. functional
2 Weeks After Planting								
Small	9.8	—	5.8	—	5	2.0	6	5.0
Medium	10.0	—	6.2	—	4	1.7	4	5.3
Large	10.5	—	5.8	—	6	1.5	5	5.5
4 Weeks After Planting								
Small	29.5	167	9.0	12	11.4	3.5	28	18.5
Medium	28.0	160	9.0	9	8.3	4.0	28	18.3
Large	26.5	161	8.5	9	12.6	4.0	31	19.5
6 Weeks After Planting								
Small	47.4	566	11.5	66	25.4	6.0	70	42.5
Medium	54.4	888	13.7	70	26.6	7.3	92	47.0
Large	53.8	818	13.5	67	24.4	6.5	104	48.0
8 Weeks After Planting								
Small	54.7	501	12.3	128	30.2	8.0	185	62.0
Medium	80.6	1,278	16.1	274	36.3	10.0	247	78.3
Large	80.2	1,590	16.5	238	34.5	11.0	301	89.0
12 Weeks After Planting								
Small	54.7	658	11.9	248	47.4	8.0	283	55.5
Medium	86.7	1,412	16.9	382	49.0	10.0	364	84.3
Large	92.1	1,764	20.4	364	50.2	12.5	445	96.0
Mature								
Small	54.7	658	11.9	248	47.4	7.9	283	60.3
Medium	86.7	1,412	16.9	380	54.4	11.6	346	84.6
Large	92.1	1,747	20.4	622	57.5	13.6	545	98.6

*For measurements inclusive of the 6th week in the small type and the 8th in the others, the leaves were held erect. Subsequent measurements were taken to the basal tassel branch.

DIFFERENCES BETWEEN TYPES AT IMMATURE STAGES

While greatest interest is attached to mature vegetative development, some noteworthy observations were made at earlier stages. Periodic measurements of a few aerial and root characters are reported for the three types in Table 6.

Vegetative development proceeded with about equal rapidity for all varieties until the small type came in tassel 7 weeks after planting.

Thereafter, development in the small type was surpassed by that of the medium and the large. Similarly, aerial and root development of the large type exceeded that of the medium as the latter approached its tasseling date 9 weeks after planting. Nearly the full stalk height, the entire area and number of leaves, all the nodes bearing roots, and the full number of functional roots were attained by all types at their respective tasseling dates; however, fodder weight, combined length of main roots, and depth of root penetration increased to maturity. Accordingly, vegetative size and lateness of maturity are correlated.

The average depth of root penetration increased 12 inches or more in all types after coming into full tassel. These depths were approximately 28, 38, and 46 inches, respectively, for the small, medium, and large varieties on their tasseling dates of 7, 9, and 11 weeks after planting, whereas they were 47, 54, and 58 inches at maturity, or the respective ages of 13, 16, and 19 weeks.

SUMMARY

The heritable characteristics of the secondary root systems of corn varieties differing materially in aboveground size when grown under comparable conditions were studied at Lincoln, Nebr. To facilitate comparisons, the varieties were grouped on the basis of size into small, medium, and large vegetative types. The mean values for certain plant measurements in the three respective types at maturity were as follows: (a) Heights of 55, 87, and 92 inches; (b) leaf areas of 658, 1,412, and 1,747 square inches; (c) moisture-free fodder weights of 248, 380, and 622 grams; (d) 88, 112, and 129 days from planting to ripening; and (e) 8, 9, and 10 stalk nodes bearing functional main roots.

The size of the secondary root system tended to increase with that of the aboveground parts. Based on the small type, the medium and large types had, respectively, (a) 33 and 50% greater maximum spread, while the average spread of main roots from that node whose roots attain the greatest average distance from the stalk was only 11 and 9% larger; (b) 9 and 10% deeper maximum penetration and 15 and 23% greater average depth of root penetration; (c) 42 and 65% more functional main roots; (d) 22 and 92% greater combined length of main roots per plant; (e) 115 and 311% greater root weight; (f) 86 and 268% greater root volume; and (g) 10 and 29% larger diameter of main roots.

Roots spreading less than 1.5 feet from the stalk were approximately 3 times as numerous in all types as those spreading more than this distance. These wide-spreading roots grew from the lowest 3, 4, and 5 nodes of the small, medium, and large varieties, respectively.

The moisture-free weight of tops in the small, medium, and large varieties, respectively, was 6.42, 4.90, and 3.47 times as great as that of the roots. From these figures, it was estimated that 445, 1,080, and 1,420 pounds of dry root material per acre were left in the soil by the current crop of the respective types.

The rapidity of root as well as top growth was approximately the same for all types until the occurrence of tasseling in the small varieties. Thereafter, more vigorous growth caused the medium and large types to surpass in these respects. Similarly, as the medium type commenced tasseling, its vegetative development was exceeded by that of the large. The outcome of this behavior is a rather high correlation between root and top growth.

LITERATURE CITED

1. Hays, Willet M. Indian corn; habits of growth; methods of planting and cultivation; notes on ears and suckers. Minn. Agr. Exp. Sta. Bul. 5 : 5–20, illus. 1889.
2. Jean, F. C. Root inheritance in peas. Bot. Gaz., 86 : 318–329, illus. 1928.
3. King, F. H. The natural distribution of roots in field soils. Ann. Rpt. Wis. Agr. Exp. Sta., 10 : 160–164, illus. 1893.
4. Miller, E. C. Plant Physiology with Reference to Green Plants. New York and London. 1931. (Page 138.)
5. Mohammad, Ali, and Deshpande, R. B. Studies in Indian chillies, (2) The root system. Agr. Jour. India, 24 : 251–258, illus. 1929.
6. Ten Eyck, M. A. Roots of plants. N. Dak. Agr. Exp. Sta. Bul. 36. 1899.
7. Venkatraman, Rao Sahib, T. S., and Vittal, Rao V. Coimbatre seedling canes. Agr. Jour. India, 23 : 37–38, illus. 1928.
8. Weaver, J. E. Root development of field crops. New York and London. 1926.

THE COMPARATIVE ROOT DEVELOPMENT OF SELFED LINES OF CORN AND THEIR F_1 AND F_2 HYBRIDS[1]

T. A. KIESSELBACH AND RALPH M. WEIHING[2]

THE hybrid vigor of first generation crosses between unrelated self-fertilized lines of corn and its reduction in the second generation is readily apparent and well known with respect to the aerial parts of the plant. The corresponding responses of the root system are more obscure and less understood. It has been the purpose of these investigations to study the extent to which heterosis may be exhibited by the root development of this crop.

DESCRIPTION OF SEED STOCKS

Two standard, homozygous lines of dent corn, Indiana B-2 and Iowa 197, and their F_1 and F_2 hybrids were studied in 1933 and a corresponding group, Illinois A and Iowa 420, and their F_1 and F_2 hybrids in 1934. These four lines are well adapted for use in hybrids suitable for eastern Nebraska conditions.

METHODS OF TESTING

Since it was the desire to limit the observations to heritable differences, the various lots were grown comparably each year with the plants spaced individually 7 feet apart in adjacent four-row plats. The tests were located on Carrington silt loam soil at Lincoln, Nebr. The plats were sweep cultivated at sufficient depth merely to destroy weeds without disturbing the main roots of the corn. The climatic conditions were conducive to normal growth in 1933. The rainfall was deficient in 1934 and supplementary irrigation was uniformly applied as needed. The root inspections were made at maturity by the use of technic recently described by Weihing.[3] Detailed observations were limited to the secondary root system since it comprises the bulk of the roots. Because of the large amount of labor involved the root examinations were confined to four plants of each selfed line and hybrid.

VEGETATIVE DIFFERENCES AT MATURITY

The customary aerial differences between selfed lines and their first and second generation hybrids are reflected in Table 1. Although the annual results for both stalks and roots are reported, the averages for the 2 years doubtless serve better to indicate mean expectations. The stalk and root development of representative plants grown in 1934 are shown in a single plane in Fig. 1.

Stalk development.—The F_1 hybrids show a material increase in the size of aboveground parts over the inbred parents, while the F_2 generation tends to be intermediate. Comparing the selfed lines, the F_1 hybrids, and the F_2 hybrids with respect to certain characters, their relative stalk heights were 100, 128, and 114; their relative

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[1] Contribution from the Department of Agronomy, Nebraska Agricultural Experiment Station, Lincoln, Nebr. Paper No. 166, Journal Series, published with the approval of the Director. Received for publication April 4, 1935.

[2] Agronomist and Assistant Agronomist, respectively.

[3] WEIHING, RALPH M. The comparative root development of regional types of corn. Jour. Amer. Soc. Agron., 27 : 526–537. 1935.

TABLE I.—*The comparative development of the stalk and the secondary root system of selfed lines* of corn and their first and second generation hybrids, 1933 and 1934.*

Inbred parents and their hybrid generations	Stalk				Main roots						
	Plant height, in.	Leaf area per plant, sq. in.	Fodder weight (moist.-free), grams	No. nodes with functional roots	Depth of penetration, ft.		Maximum spread†, ft.	Combined length, ft.	Number	Mean‡ diameter, mm	No. root-branches per inch
					Av. all roots	Maximum					
					1933						
Ind. B-2	67	806	272	9	3.0	4.2	3.6	295	60	1.8	14.1
Iowa 197	71	878	245	9	3.4	4.5	3.0	255	68	1.7	15.8
F_1	88	1077	433	9	4.3	5.8	3.7	361	76	2.2	13.3
F_2	74	945	347	9	3.8	5.1	3.7	341	74	2.0	13.4
					1934						
Ill. A	72	561	86	11	3.1	4.2	2.1	409	107	1.2	13.1
Iowa 420	79	759	181	9	3.1	4.1	3.7	354	80	1.3	11.2
F_1	96	1066	411	10	4.9	7.2	3.4	590	96	1.6	11.7
F_2	90	795	298	9	4.0	5.8	2.5	450	94	1.4	12.2
					Average for 2 Years						
Inbreds	72	751	196	9.5	3.2	4.2	3.1	328	79	1.5	13.6
F_1	92	1072	422	9.5	4.6	6.5	3.6	476	86	1.9	12.5
F_2	82	870	322	9.0	3.9	5.4	3.1	396	84	1.7	12.8

*The selfed lines have been continued by inbreeding in Nebraska for a number of generations from seed originally secured from J. R. Holbert and M. T. Jenkins of the U. S. Dept. of Agriculture.

†Root spread represents the distance from base of the stalk to the farthest lateral point.

‡Average of measurements near the base, midpoint, and tip of all main roots.

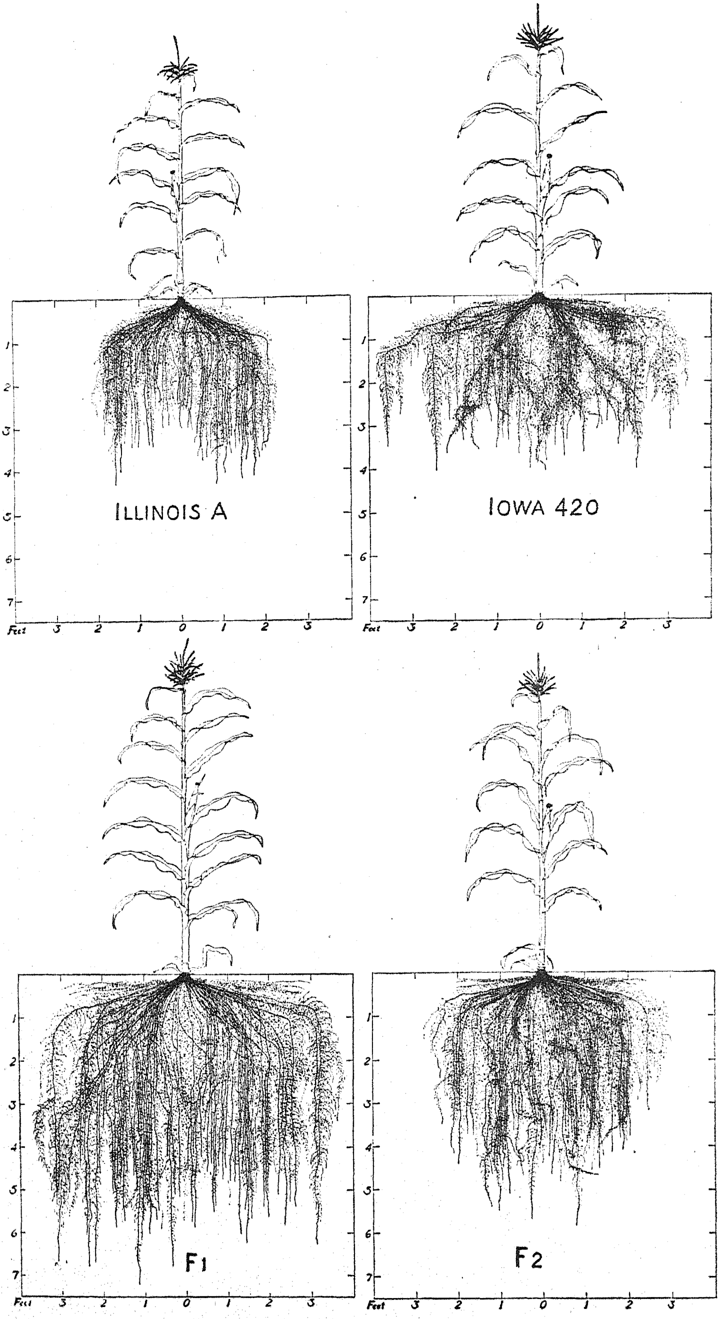

FIG. 1.—Representative plants of the selfed lines Illinois A and Iowa 420 and the F_1 and F_2 hybrids between them. Approximately 25% of the branch roots are shown.

leaf areas per plant 100, 143, and 116; and their relative moisture-free fodder weights 100, 215, and 164.

Root development.—Upon hybridization, the depth of penetration, the combined length of all main roots per plant, and the diameter of main roots (Table 1) increased materially in the first generation, while in the second generation they were intermediate. Thus, comparing the selfed lines and the first and second generation hybrids, the relative maximum root penetrations were, respectively, 100, 155, and 129; the relative mean penetrations of all roots per plant 100, 144, and 122; the relative combined lengths of all the main roots per plant 100, 145, and 121; and the relative mean root diameters 100, 127, and 113. The corresponding relative maximum root spread of the three types was, respectively, 100, 116, and 100. Upon hybridization the number of branches per unit length of main roots decreased 8 and 6%, respectively, in the first and second generations. This may undoubtedly be accounted for by the tendency of individual cells of hybrids to grow larger as found by Kiesselbach,[4] causing a wider separation of the branch roots.

It is evident that inbred lines may differ materially in some root characters as number of main roots per plant, number of branches per unit length of main root, and lateral root spread. In general, the root development in subsequent hybrid generations exhibits heterosis, as does stalk development.

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[4] KIESSELBACH, T. A. Corn investigations. Nebr. Agr. Exp. Sta. Res. Bul. 20. 1922.

RELATIVE PROMPTNESS OF NODULE FORMATION AMONG VETCHES, VETCHLINGS, WINTER PEAS, CLOVERS, MELILOTS, AND MEDICS[1]

J. F. DUGGAR[2]

THE conditions under which root nodules develop most readily on the roots of leguminous plants have been less intensively studied than the importance of the subject warrants. The more elaborate of the investigations have been conducted in the laboratory, where the host legumes necessarily have been subjected to highly artificial conditions. These and other considerations pointed to the need for supplementary investigations to supply data on the development of root nodules under field conditions, hence a series of field experiments has been conducted for a number of years on the Experiment Station farm at Auburn, Ala.[3]

This paper is a report on one of a series of field studies to determine to what extent, if at all, winter legumes differ among themselves in their promptness or tardiness in developing root tubercles when planted in the field at usual or typical dates in the fall.

METHODS

Two plantings of all species were made each year, the first as near to October 1 and the second to November 1, as practicable. The seed were planted in rows 3 feet apart at a depth of 2 inches for the vetch group and of 1 inch for the small-seeded group. This field, of Norfolk sandy loam, was annually prepared, fertilized, and cropped as uniformly as possible. Phosphate in moderate amount was applied early each year and out of contact with the seed. Samples consisting of as many plants as practicable were collected at intervals of one to several days from three or more locations on each plat and the nodules were counted.

Generalized nodulation was considered as occurring when 85% or more of the plants of a given sample were found to bear one nodule or more. The day when a considerable percentage of the young seedlings came up and were thus first exposed to light was taken as the day of emergence. The term "nodulation period" is here used to designate the interval between emergence and generalized nodulation as defined above.

Seed of all species and for every date of planting were artificially inoculated by soaking them for about an hour in a suspension of the appropriate inoculum. Humus cultures from the same manufacturer were used each year on seed of all species. The micro-organisms appropriate to the vetches were widely distributed in this soil throughout the experimental period; but the bacteria suited to the clovers, melilots, and medics were absent or very scarce.

RESULTS

VETCHES, VETCHLINGS, AND WINTER PEAS

The average number of days between emergence and generalized nodulation of each species is shown in Table 1.

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[1] Contribution from the Department of Special Investigations, Alabama Agricultural Experiment Station, Auburn, Ala. Received for publication April 8, 1935.

[2] Research Professor.

[3] DUGGAR, J. F. Preliminary notes on time of nodulation of winter legumes. Ala. Agr. Exp. Sta., Ann. Rpts., 1926:22; 1927:26; and 1929: 25–26.

TABLE I.—*Number of days between emergence and generalized nodulation for early October and early November plantings of vetches, vetchlings, and winter peas, 1926–1931.*

Kind of legume	Number of days in nodulation period from plantings made in		
	Early Oct.	Early Nov.	Av. of Oct. and Nov.
Wooly-pod vetch (*V. dasycarpa*)	6	7	6.5
Hungarian vetch (*V. pannonica*)	7	7	7.0
Hairy vetch (*V. villosa*)	7	8	7.5
Monantha vetch (*V. monantha*)	6	9	7.5
Oregon vetch (*V. sativa*)	6	10	8.0
Narrow-leaved vetch, northern (*V. angustifolia*)	8	9	8.5
Austrian pea (*Pisum sativum*)	7	10	8.5
Narrow-leaved vetch, southern (*V. angustifolia*)	9	9	9.0
Tangier pea (*Lathyrus tingitanus*)	7	12	9.5
Purple vetch (*V. atropurpurea*)	8	12	10.0
Pearl vetch (*V. sativa*)	11	11	11.0
Bitter vetch (*V. ervilia*)	10	16	13.0
Lentil (*Ervum lens*)	12	14	13.0
Scotch vetch (*V. sativa*)	14	13	13.5
Sweet pea (*L. odoratus*)	17	22	19.5
Horse bean, small seeded (*V. faba*)	19	25	22.0
Grass pea, late white (*Lathyrus sativus*)	14	32	23.0
Grass pea, early white (*L. sativus*)	12	37	23.5

The various cultivated species of vetches, vetchlings (*Lathyrus* sp.), and Austrian winter pea differed materially in their promptness in forming root nodules. Woolly-pod, Hungarian, hairy, monantha, Oregon, and narrow-leaved vetches, and Austrian pea were almost always very prompt in attaining generalized nodulation. The average time that they required between emergence and generalized nodulation was 6½ to 8½ days. Tangier pea, purple vetch, and Pearl vetch followed closely with nodulation periods that averaged 9½ to 11 days under these conditions. Bitter vetch and Scotch vetch, with average nodulation periods of 13 and 13½ days, were distinctly later in nodulation than other vetches. Sweet pea, horse bean, and grass pea, with average nodulation periods of 19½, 22, and 23½ days, respectively, were slowest in reaching generalized nodulation. Species was obviously one of the factors determining the promptness or tardiness of nodule formation.

The most surprising contrast in the time required for generalized nodulation was afforded by a comparison of Oregon and Scotch vetches. To become moderately stocked with root nodules, Oregon vetch required on an average only 8 days against 13.5 days for Scotch vetch. These are in the same species (*V. sativa*) and the young plants are indistinguishable. Their chief agronomic differences were found here to consist of much greater earliness for the Scotch vetch and a far greater susceptibility of this strain to injury from low winter temperatures. Apparently variety, as well as species and genera, may affect nodulation.

CLOVER, MEDICS, AND MELILOTS

The average number of days from emergence to generalized nodulation of each species of numerous clovers, medics, and melilots is shown in Table 2.

TABLE 2.—*Number of days between emergence and generalized nodulation for October and November plantings of clovers, meliots, and medics, 1926–1931.*

Kind of legume	Average number of days in nodulation period from plantings made in		
	Early Oct.	Early Nov.	Av. of Oct. and Nov.
Crimson clover (*T. incarnatum*)	31	23	27
Red clover (*T. pratense*)	28	41	34
Alsike clover (*T. hybridum*)	22	21	21
White Dutch clover (*T. repens*)	33	16	24
Ladino clover (*T. repens latum*)	23	23	23
Subterranean clover (*T. subterraneum*)	20	20	20
White biennial melilotus (*Melilotus alba*)	29	21	25
Yellow annual melilotus (*M. indica*)	29	46	37
Early bur clover, spotted leaf (*Medicago arabica*)	11	35	23
California bur clover (*M. hispida*)	28	49	38
Alfalfa, average of common, Grimm, and Hairy Peruvian (*M. sativa*)	26	43	34

The clovers, melilots, and medics presented no marked and constant difference in rate of nodulation that might be attributed to diversity in genera. There were greater differences among individual species within the same genera than between any two genera. Specific difference between *Medicago arabica* and *M. hispida* may be noted.

DISCUSSION

Every species of clover, melilot, and medic tested required a much longer average time to attain a stage of generalized nodulation than did representative species in the vetch group. This difference may be due to any one or more of the following factors: Specific visible dissimilarities in the two classes of host plants, inherent unidentified differences among the hosts, and variations in environment. The plants of the vetch group made more extensive early growth of both tops and roots, due in part to larger reserves contained in the seeds. Their environment was also somewhat more favorable in one respect. They were free to utilize not alone the appropriate inoculum, which was supplied to all seeds of both classes, but the vetches were able also to make use of the vetch bacteria that were abundant in this soil as the result of the earlier growth of narrow-leaved vetch. No corresponding supply was available in this acid soil (pH 4.7 to 5.3) of micro-organisms suitable to the clovers, melilots, and medics. It seems probable that any adverse condition, such as too great acidity or dryness, would more effectively reduce or delay nodule formation that results merely from inoculation of seed than it would be able to restrict nodule development due to bacteria carried by both seed and soil.

Specific differences were shown in the readiness with which different species within the same genus became stocked with root nodules. For example, bitter vetch (*V. ervilia*) required 13 days for generalized nodulation against 6.5 to 8 days for most other species of *Vicia*. Moreover, California bur clover (*Medicago hispida*) required 38 days for generalized nodulation against 23 days for spotted-leaf bur clover (*M. Arabica*).

SUMMARY

Artificially inoculated seed of numerous species of vetches, vetchlings, winter peas, clovers, melilots, and medics were planted twice each fall through a 6-year period. Frequent counts of root nodules were made.

Average figures are presented which show for each species the length of time between the emergence of each lot of seedings and generalized nodulation.

The vetches showed significant differences among species in the length of time required to attain a condition of generalized nodulation.

Leading in promptness of nodule formation were woolly-pod, Hungarian, hairy, Monantha, Oregon, and narrow-leaved vetches, and Austrian pea, with averages of only 6½ to 8½ days from emergence to the stage of generalized nodulation.

These were rather closely followed by Tangier pea, purple vetch, and Pearl vetch, which required an average of 9½ to 11 days.

Slowest of the "vetch group" species were sweet pea, horse bean, and grass pea, with average initial nodulation periods of 19½ to 23½ days.

The nodulation periods of bitter vetch and lentil were of intermediate length, with averages of 13 days each.

Scotch vetch, a very early strain, had an average nodulation period of 13½ days, or nearly 70% longer than that of Oregon vetch. These are both strains of *Vicia sativa*.

The interval between emergence and generalized nodulation was longer for the clovers, melilots, and medics than for typical vetches. This dissimilarity is attributed partly to specific characteristics of the host legumes and partly to difference in the kinds of bacteria in the soil.

A NEW LEGUME IN MONTANA[1]

J. R. GREEN AND H. E. MORRIS[2]

A NEW legume (*Astragalus* sp.) was found growing on some farms in the Ruby Valley in the vicinities of Waterloo and Twin Bridges, Mont. Records indicate that it attracted attention on the farm of John Masolo near Waterloo about 6 years ago. It thrived in a high-lime soil on moist bottomland containing more or less alkali (Table 1), where the water table was 3 feet or less from the surface.

TABLE 1.—*Alkali salts in soil on which new legume is growing.**

Depth of sample	Sulfates as Na_2SO_4		Carbonates as Na_2CO_3		Chlorides as NaCl		Total
	%	Pounds per acre foot	%	Pounds per acre foot	%	Pounds per acre foot	
			Sample No. 1				
1st foot....	0.393	13,755	0.019	665	0.048	1,680	
2nd foot...	0.077	2,695	0.013	455	0.010	350	
3rd foot...	0.057	1,995	0.011	385	0.008	280	
4th foot...	0.055	1,925	0.013	455	0.006	210	
Total...	—	20,370	—	1,960	—	2,520	24,850
			Sample No. 2				
1st foot....	0.190	6,650	0.016	560	0.016	560	
2nd foot...	0.104	3,640	0.011	385	0.008	280	
3rd foot...	0.042	1,470	0.011	385	0.005	175	
4th foot...	0.042	1,470	0.011	385	0.003	105	
Total...	—	13,230	—	1,715	—	1,120	16,065
			Sample No. 3				
1st foot....	1.211	42,385	0.027	945	0.157	5,495	
2nd foot...	0.225	7,875	0.011	385	0.035	1,225	
3rd foot...	0.067	2,345	0.011	385	0.008	280	
4th foot...	0.060	2,100	0.011	385	0.006	210	
Total...	—	54,705	—	2,100	—	7,210	64,015

*Sulfates, carbonates, and chlorides determined as the ions and calculated as percentage and total sodium salts in one acre foot, 3,500,000 pounds being taken as the weight to one acre foot.

About a year ago this plant was called to the attention of the writers by John Ruppel of Twin Bridges because it was producing a considerable amount of palatable forage of apparently good quality.

This wild pea makes an abundant growth from the crown of a woody root (Fig. 1). It spreads out over the ground for 2 to 3 feet as a dense mat and soon crowds out other vegetation, forming relatively pure stands. The slender stems of the plant may grow to 4 feet

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[1] Contribution from Montana, Agricultural Experiment Station, Bozeman, Mont. Paper No. 49, Journal Series. Received for publication April 8, 1935.

[2] Chemist and Botanist, respectively.

in length and bear many leaves 3 to 5 inches long (Fig. 2). Each leaf has about six pairs of leaflets and a terminal leaflet. Each leaflet is about 1 inch long and ½ inch wide. It is a very prolific producer of seed, each being about the size of an alfalfa seed.

The roots are similar to those of alfalfa and bear many nodules. The flowers are small, less than ¼ inch long, purplish in color, and like a pea flower. The pods are small, numerous, about ¾ inch long, and usually contain about 10 seeds. The growth is indeterminate; therefore there are mature pods, immature pods, and flowers occurring on the same stem.

On several ranches in the Ruby Valley this wild pea has been cut, cured, and stacked like alfalfa. The yield of hay from this plant has not been determined, but there is no doubt that it has materially increased the production of forage on the ranches where it occurs. It will probably never rival alfalfa in hay production as it produces only one hay crop a year; however, it does thrive on land that is not suitable for alfalfa, and all reports indicate that the hay is of high quality and that all kinds of stock seem to relish it.

Feed analyses made by the authors (Table 2) show that it is like alfalfa as regards its content of protein, nitrogen-free extract, crude fiber, ether extract, and ash. Another characteristic of this plant is that it contains a high percentage of phosphorus, considerably higher than alfalfa growing in the same region. This is very important because the soil generally in this particular section is deficient in phosphorus and livestock often show the effect of phosphorus-deficiency when fed only native

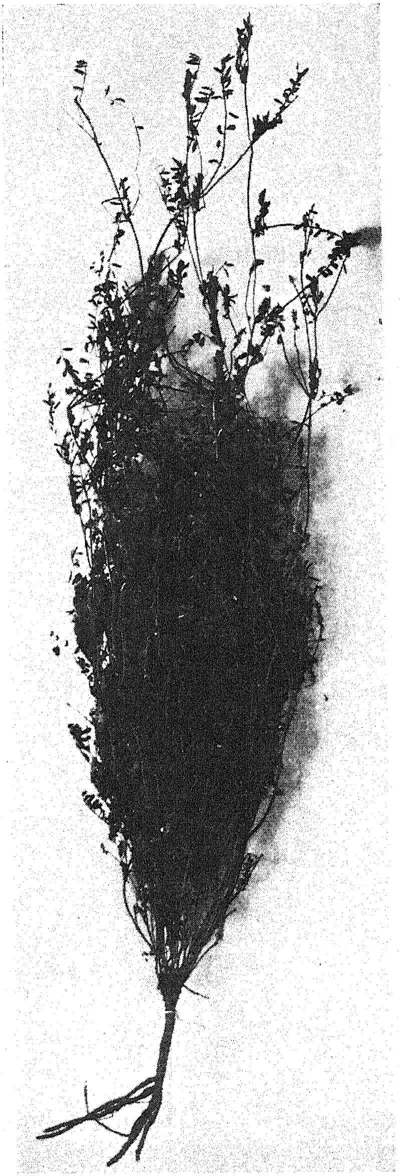

FIG. 1.—*Astragalus rubyi* sp. nov. found in Montana. X 1/11.

grass. This plant, however, accumulates a large supply of phosphorus from this soil.

TABLE 2.—*Feed analyses of new legume.*

Description of sample	Protein %	Ash %	Ether extract %	Crude fiber %	Nitrogen-free extract %	P_2O_5 %
No. 1, composite of large plants of new legume from Farm B*.	14.12	10.5	2.2	27.47	45.71	0.389
No. 2, composite of large plants of new legume from Farm M*.	14.56	14.2	2.2	23.57	45.47	0.345
Av. 9 samples of alfalfa growing in same locality as the new legume.	—	—	—	—	—	0.244
Av. Montana alfalfa.	16.48	8.73	1.53	33.39	39.87	0.500
Av. Montana sweet clover. .	15.73	7.64	1.66	31.93	43.50	—

*The samples of the new legume were cut at an advanced stage and thus the protein content is lower than if the plants had been cut earlier in the season. From the standpoint of the feed analyses it is very high in carbohydrates or nitrogen-free extract. Also, the phosphorus content (P_2O_5) is high for a feed growing on this particular soil.

Cultural experiments in comparison with alfalfa and other important forages must be conducted to determine the range of its adaptability in regard to climate and soil. In addition, feeding experiments are needed to verify the reports of farmers regarding palatability and nutritive value. The results of such studies may show that this plant can have an important economic place in reclaiming low, damp bottom-land in the higher mountain valleys in Montana

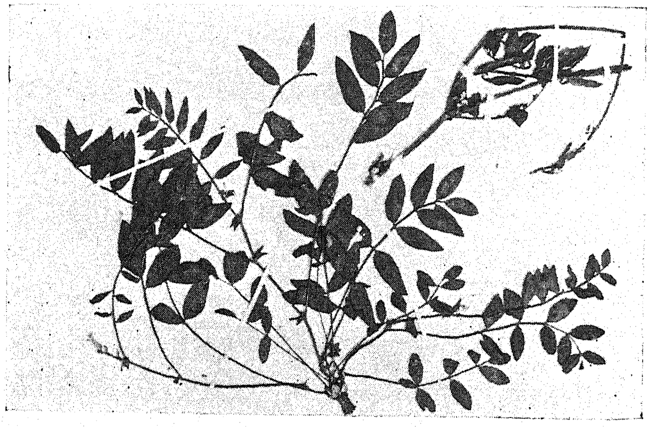

FIG. 2.—Young plant of *Astragalus rubyi* sp. nov. as found in Montana. X 3/10.

and elsewhere. It may be used either as a forage or as a soiling crop. Attempts to identify this plant have been unsuccessful, therefore a description of the plant has been submitted for publication elsewhere under the name *Astragalus rubyi* sp. nov. Further studies of this plant are being made.

LIGHT INTENSITY AS AN INHIBITING FACTOR IN THE FIXATION OF ATMOSPHERIC NITROGEN BY MANCHU SOYBEANS[1]

FRED S. ORCUTT AND E. B. FRED[2]

RECENT biochemical studies indicate that the symbiotic association of rhizobia and leguminous plants is intimately related to the carbon-nitrogen balance in the plants. The results from many types of experiments (3)[3] indicate that an increase in carbohydrate synthesis favors fixation of nitrogen. A discussion of the literature on this subject is given by Wilson (7).

In most of the previous work emphasis is laid upon the stimulating effect of carbohydrate synthesis on nitrogen fixation; and the conclusion may be reached that any factor, e. g., light intensity or day length, that will increase the carbohydrate level in the plant will likewise *increase* nodule formation and nitrogen fixation. Conversely, any method which decreases the carbohydrate concentration, such as short exposure to light and addition of combined nitrogen to the substrate, will also *lower* nodule production and total nitrogen fixed.

In view of the evidence that nodule formation and nitrogen fixation are related to the photosynthetic activity of the plant, and since photosynthesis within limits is apparently proportional to light conditions, it appears reasonable to assume that light conditions and nitrogen fixation should have a positive correlation. The experiments reported in this paper were designed to measure the relation between light conditions and nitrogen fixation.

METHODS

Plant culture.—The plants were grown in glazed jars containing 11 kilos each of dry, sterilized, leached pit sand which contained no hot water extractable nitrogenous material. The soybean seed, of the Manchu variety, was sterilized by the method of Hopkins, Wilson, and Fred (4), planted in the bacterial-free sand to which had been added distilled water, and an aqueous suspension of a tested strain of *Rhizobium japonicum* added to jars to be inoculated. Enough seeds were planted so that 7 to 10 healthy plants could be obtained after thinning. The plants were watered with distilled water, and nitrogen-free Crone's solution (1) was added once a week.

Analytical—All plants were harvested early in the morning, from 7:00 to 9:00 o'clock. Leaves and stems were clipped and placed in a drying room at 60° C, roots were washed out of the sand with a stream of water, immersed in brine several minutes to loosen sand particles, and rinsed. Nodules were removed and both were dried at 60° C.

Total nitrogen was determined on an aliquot of the ground plant material by the official A. O. A. C. method. Samples in the first experiment were dried at 80° C for carbohydrate determinations. Total sugars were found by the Stiles,

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[1] Contribution from the Departments of Agricultural Bacteriology and Agricultural Chemistry, University of Wisconsin, Madison, Wis. Herman Frasch Foundation in Agricultural Chemistry, Paper No. 95. Received for publication April 15, 1935.

[2] Research Assistant and Professor of Agricultural Bacteriology, respectively.

[3] Figures in parenthesis refer to "Literature Cited", p. 558.

Peterson, and Fred (5) modification of the Shaffer-Hartman micro method. Light intensities were measured by the Weston Illumination Meter, Model 603.

EXPERIMENTAL

EXPERIMENT I. JUNE 1 TO JULY 13, 1932

Forty 2-gallon jars containing seven plants each were set up outside in a cold frame. The plants were divided into two groups for the following treatments: (a) Inoculated with nodule bacteria, and (b) given ammonium nitrate but no nodule bacteria. The nitrate was added at the rate of 25 mgm. of nitrogen three times a week, since this amount was sufficient to support the needs of the plants in each jar. During the growing period the days were unusually hot and the sun intensity approached a maximum. Although the soybeans had an abundance of nodules, they failed to initiate fixation of nitrogen. The nodules were large, well formed, and situated near the crown—the position usually associated with optimum fixation of nitrogen.

The gross appearance of the plants was yellow and pale green, stunted, stalky and dry, while uninoculated plants receiving ammonium nitrate under the same light conditions were growing tall, good green color, and succulent. At 5 weeks it was noticed that a few inoculated plants which were shaded from the direct rays of the sun during a short portion of the day were somewhat greener and more thrifty; evidently high light intensity was inhibiting either fixation or assimilation in the inoculated plants. To test this hypothesis a shield of heavily white-washed glass was erected to cut off the direct sun rays from one-half of each series of plants—inoculated and those receiving ammonium nitrate. There was at all times, however, an abundance of sky and reflected light. Two to 3 days after this change a very marked effect was noticeable in color, height, and succulence. After exactly *1 week* of shading, the plants were harvested (6 weeks from sprouting) and four representative jars were photographed from the inoculated series—two shaded and two unshaded (Fig. 1). The difference in height, color intensity, and leaf area is apparent. The root system of the shaded plants had nearly doubled in a week's time. The nodular development in both shaded and unshaded plants appeared to be equally good.

EXPERIMENT II

In the summer of 1933 a study was made of nitrogen fixation in soybeans under different light conditions, *viz.*, reduced intensity and short days as compared with full intensity and long day exposure. Plants were grown outside in a cold frame, all inoculated and then divided into the following treatments:

Group	Age	Treatment	Number of plants	Date of harvest
1	4 weeks	Unshaded	51	July 2
2	5 weeks	Unshaded	100	July 10
3	5 weeks	Shaded 1 week before harvest	50	July 10
4	5 weeks	Shaded 2 weeks before harvest	50	July 10
5	5 weeks	Short day	30	July 10

The controls harvested at 4 weeks, group 1, represent the condition of group 3 when shading was started. Group 4 had already been shaded 1 week by this time.

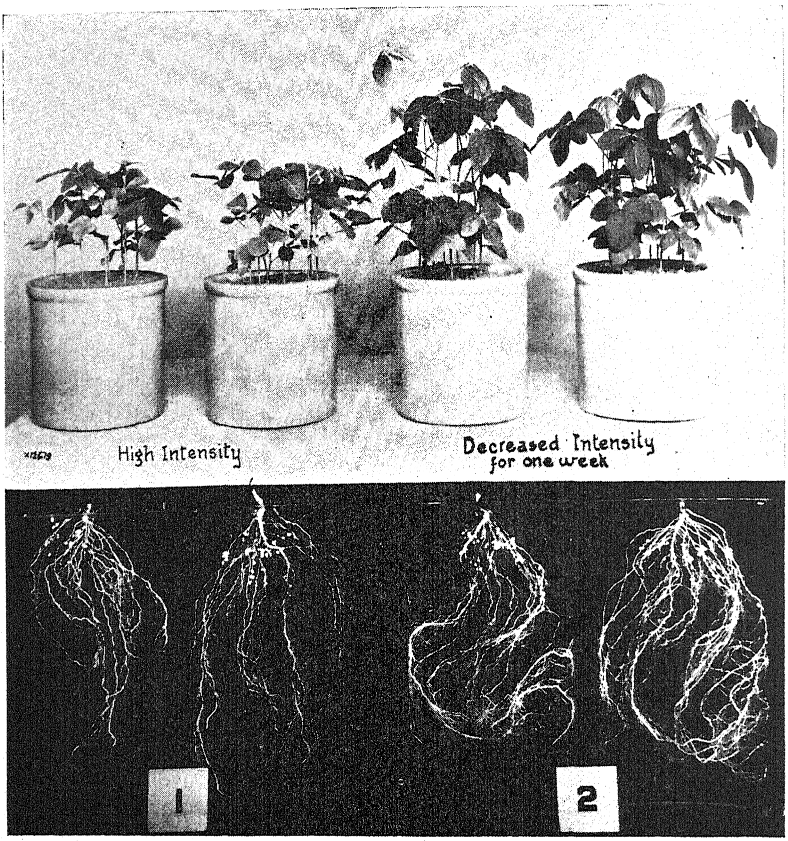

Fig. 1.—Effect of shading for 1 week on inoculated soybean plants grown in nitrogen-free sand.

Shading from the direct sun rays was accomplished with white-washed glass as in Experiment I. The light intensity under shaded conditions averaged 2,000 foot candles, and under normal conditions averaged better than 8,000 foot candles (measurements were made between 10 a.m. and 2 p.m.).

The temperature of the sand in groups 1 and 2 *just below the surface* reached a maximum of approximately 37°C shortly after mid-day. The corresponding temperature for shaded pots was approximately 35° C. The temperature decreased with the distance from the surface of the sand. The short day plants were given light from 9:00 in the morning until 4:30 in the afternoon. After this time the temperature just below the surface of the pots in the dark chamber was approximately 5° C less than in those exposed to the sun.

EXPERIMENT III

This was much the same as the previous experiment. The plants were grouped as follows:

Group	Age	Treatment	Number of plants		Date of harvest
			Rh. japonicum strain 504	*Rh. japonicum* strain 10	
1	5 weeks	Unshaded	68	53	Aug. 7
2	5½ weeks	Unshaded	68	67	Aug. 11
3	5½ weeks	Shaded 4 days before harvest	67	54	Aug. 11
4	6 weeks	Unshaded	41	54	Aug. 14
5	6 weeks	Shaded 1 week before harvest	48	51	Aug. 14
6	6 weeks	Shaded 2 weeks before harvest	39	66	Aug. 14
7	6 weeks	Short day	41	41	Aug. 14

The controls, unshaded plants, harvested at five weeks represent the condition of 4- and 7-day shaded plants at the start of shading. The 14-day shaded plants had already been shaded 7 days by this time.

The light intensity under shaded conditions averaged 2,000 foot candles and under normal conditions 6,000 to 7,500 foot candles. The short day plants were darkened to an intensity of less than 4 foot candles when not exposed to full sunlight. Temperature observations were much the same as in Experiment II.

SUMMARY OF RESULTS

The absolute values for total nitrogen and dry weight per plant, as well as the soluble sugar levels, are given in Fig. 2 for the first experiment. It is apparent from the various staffs for total nitrogen per plant that the inoculated plants benefited by shading, whereas the reverse was true in uninoculated plants receiving nitrate. In the inoculated series, the nitrogen fixed per plant was 21.7 mgm. more in plants shaded 1 week than in those that were unshaded. The amount of nitrogen fixed in shaded plants was 116% greater than in those under higher light intensity. The same relationship as was found for total nitrogen was also true for dry weight. In inoculated plants there was a greater dry weight with shading, i. e., 590 mgm. per plant, or an increase of 43%. In contrast to this, the plants receiving nitrate were lower in dry weight with shading than the controls, i. e., 638 mgm. per plant, or 24% lower. This is the normal and expected response to decreased light intensity.

The concentration of sugars would be expected to decrease with decreasing intensity, but the staffs for sugar percentage show a much greater drop with shading in inoculated plants than in those receiving nitrate. This is correlated with the greatly increased fixation of nitrogen with shading. The appearance alone of these inoculated plants was sufficient to conclude that high intensity inhibited fixation, while reduced intensity for the short period before harvest accelerated the fixation process (Fig. 1).

The differences in Experiment II were similar to those of Experiment I, although not as striking. The data for total nitrogen and dry

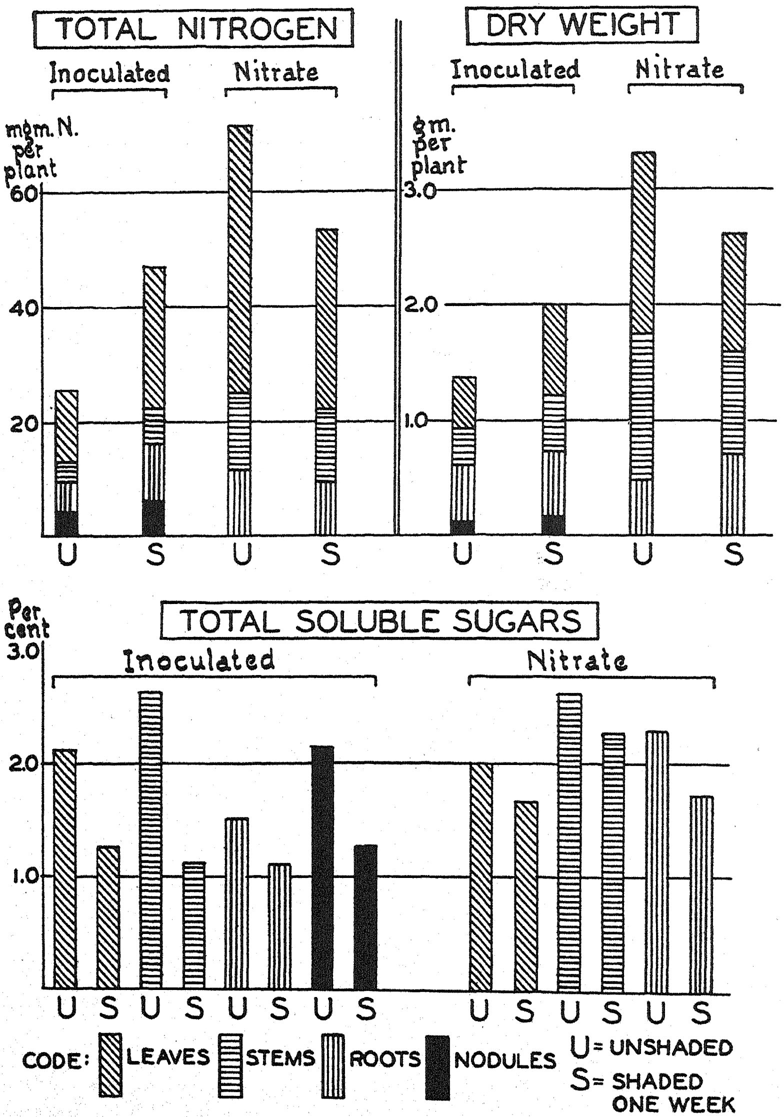

FIG. 2.—Effect of shading for 1 week on the total nitrogen, dry weight, and carbohydrate level of soybeans—inoculated plants vs. those receiving nitrate.

weight are plotted in the upper half of Fig. 3. The four staffs under "5 weeks" represent the various treatments. Plants shaded 1 week showed 25%, or 9.2 mgm., more nitrogen fixed per plant and 15%, or 270 mgm., more dry weight per plant than the unshaded controls at higher light intensity. The staff at the left of each major section, i. e.,

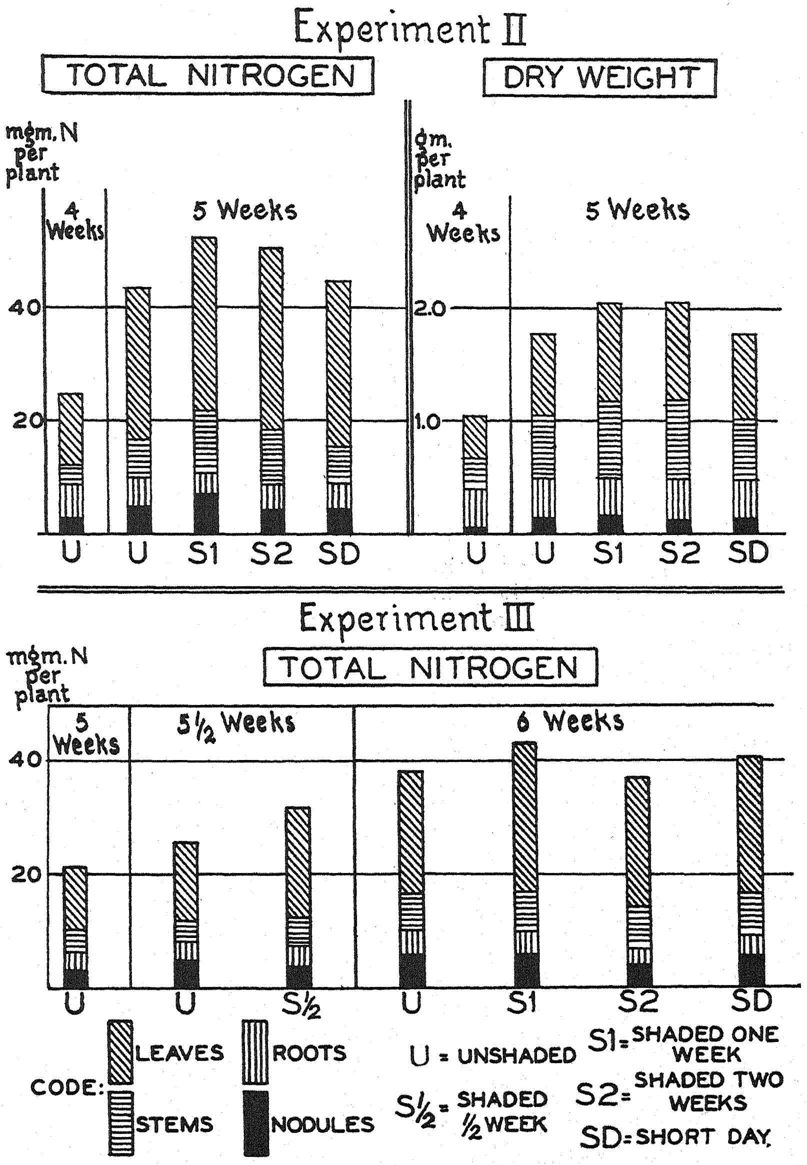

FIG. 3.—Effect of shading for short intervals on total nitrogen and dry weight of inoculated soybean plants.

under "4 weeks", represents the condition of these plants at the start of shading. The plants shaded 2 weeks showed 18%, or 6.5 mgm., more nitrogen fixed and 16% or 280 mgm., more dry weight per plant than unshaded controls. The short day plants showed no appreciable difference in dry weight or total nitrogen from the plants under normal conditions.

Experiment III was carried out in the middle to late summer under somewhat less light intensity than Experiment II. These data are plotted in the lower half of Fig. 3. The plants shaded 4 days and harvested at 5½ weeks showed 31%, or 5.8 mgm., more nitrogen per plant than the unshaded plants. The plants shaded 1 week and harvested at 6 weeks showed 4.4 mgm. more nitrogen per plant than the unshaded controls. The nitrogen in plants shaded 2 weeks in this experiment, however, was slightly less than controls (1.9 mgm); in this case carbohydrate probably became the limiting factor. The short day plants, as in Experiment II, showed no gain or loss in nitrogen over plants under normal conditions. No gains in dry weight were noted.

DISCUSSION

The shading of plants normally brings about a lower dry weight and sugar level than normal as found in the plants receiving nitrate in the first of these experiments. In the case of the inoculated soybeans, however, it was found that under normal high light intensity of early summer the plants were very slow in initiating the fixation process. As a result the plants had a high excess of carbohydrate as evidenced by the yellow leaves and anthocyanin formation in the stems. By partially reducing the light intensity an immediate growth response was noted in the plants as seen in Fig. 1, so that the dry weight and total nitrogen fixed were materially increased. It is a common observation that while soybeans grown in sand culture in the early summer undergo this nitrogen hunger period before fixation commences no such yellowing is noted in the late summer and fall; or at least such a corresponding condition in the fall is much less noticeable and of comparatively short duration. One of the outstanding differences in environmental conditions between early summer and fall is the difference in duration and intensity of light so that the differences noted might be ascribed to this factor. The average intensity in Madison in gram calories per square centimeter falls from 16,000 in June and July to 10,000 in September and 7,000 in October. The average daily sunlight in hours is 9.9 and 10.3 for June and July, respectively. The corresponding figures for September and October are 7.3 and 5.6, respectively. The amount of radiant energy in the fall, therefore, in much less than in the spring and early summer. The possibility that the nitrogen lag period noted in legumes may be due to this light factor is supported by evidence given in these experiments. Plants in the yellow, low nitrogen condition were virtually brought out of this starvation period by reducing the light intensity received by the plants; and in addition, plants under continually shaded conditions, as well as short day plants, did not enter this period of yellowing. The increases in nitrogen fixed and dry weight per plant substantiate these superficial observations.

A statistical treatment of data obtained in these three experiments gives further indication of the detrimental effect of extremely high carbohydrate within the plant. For each treatment within a given experiment, the following correlation coefficients were calculated: The relative *percentage of nitrogen* with (a) relative *nitrogen fixed per gram of nodular material*, (b) relative *nitrogen fixed per gram of plant material*, and (c) relative *nitrogen fixed per plant*. The first plants harvested in each experiment which were grown under normal light intensity were taken as the control (equals 100), and the relative values, referred to above, calculated.

Table 1 summarizes the data. For each correlation the statistic Z and its standard deviation were estimated, and the values or r corresponding to the values $Z \pm 2\sigma_Z$ determined (2). These values, given in the last two columns of the table, represent the probable range of r.

TABLE 1.—*Correlations between relative percentage of nitrogen and relative nitrogen fixed.*

Correlation between percentage nitrogen and	r	Z	Probable range of r	
			Upper	Lower
Relative mgm. N fixed:				
Per gram of plant material	0.921	1.567	0.971	0.775
Per gram of nodules	0.868	1.298	0.950	0.644
Per plant	0.637	0.733	0.852	0.207

$n^1 = 17.$ $\sigma_Z = 0.267.$

These values for r indicate that a high *positive* correlation exists between the relative percentage of nitrogen and the relative quantity of nitrogen fixed determined on the three bases. The correlation with relative mgm. of nitrogen per plant, although quite definitely positive, was significantly lower than the other two bases used.

The percentage of nitrogen may be taken as a *negative* index of the carbohydrate level so that the observed correlations may be used as derived correlations between nitrogen fixed and the carbohydrate level. Since the values of r show a high *positive* correlation between nitrogen fixed and nitrogen percentage, they indicate a high *negative* correlation between carbohydrate level and nitrogen fixed.

This appears to be a reversal of the findings of Fred and Wilson (3) whose data indicated a *positive* correlation between increasing carbohydrate and number of nodules; and since number of nodules is positively correlated with nitrogen fixed (6), it would be expected that increasing carbohydrate would also increase nitrogen fixation.

The discrepancy between the results of these various workers and the present experiments may be explained by the different carbohydrate-nitrogen ratios dealt with in the two different types of experiments. When the plant is relatively rich in nitrogen, the fixation may be increased by making more carbohydrate available for protein formation and bacterial requirements; but when the carbon-nitrogen ratio becomes excessive the fixation is retarded if not completely inhibited. Fred and Wilson (3) suggest that the carbon-nitrogen ratio becomes so over-balanced that the "available nitrogen is tied up and thus retards the development of the fixation centers." It is further suggested that the high carbon-nitrogen ratio tends to produce a non-succulent plant and the carbohydrate is condensed in storage forms which are relatively unavailable for protein formation from any nitrogen which might be fixed. This hypothesis is supported by the observation, in the first experiment in particular, that the nodules on the nitrogen-deficient plants appeared to be as large and as well formed as those found on shaded plants where fixation was known to have taken place. It is suggested, then, that the high carbon-nitrogen ratio brings about a non-succulent plant whose translocatory powers are greatly diminished and whose carbohydrate has become relatively fixed in the tissues in a dehydrated, non-translocatory form.

It appears probable, from the evidence thus far presented, that neither high nor low carbon-nitrogen ratios favor fixation of nitrogen. On the other hand, there seems to be an optimum somewhere between these two extremes where the fixation activity is favored.

SUMMARY

1. Inoculated soybeans grown (in nitrogen-free sand) under normal high light intensity of early summer failed to initiate the process of nitrogen fixation. Partial shading for 1 week brought the plants out of this fixation lag period.

2. Experience from the work of two summers made it appear that this was correlated with the carbon-nitrogen relation within the plant. A statistical treatment of the data obtained in this type of experiment indicates a high *negative* correlation between the carbohydrate level and nitrogen fixed. It is concluded that an extremely *high* carbon-nitrogen ratio in the plant inhibits nitrogen fixation similar to the inhibition observed with extremely *low* carbon-nitrogen ratios.

LITERATURE CITED

1. Bryan, O. C. Effect of different reactions on the growth and nodule formation of soybeans. Soil Science, 13: 271–287. 1922.
2. Fisher, R. A. Statistical Methods for Research Workers. Edinburgh; Oliver & Boyd. Ed. 3. 1930.
3. Fred, E. B., and Wilson, P. W. On photosynthesis and free nitrogen assimilation by leguminous plants. Proc. Nat. Acad. Sci., 20 : 403–409. 1934
4. Hopkins, E. W., Wilson, P. W., and Fred, E. B. A method for the growth of leguminous plants under bacteriologically controlled conditions. Jour. Amer. Soc. Agron., 23 : 32–40. 1931.
5. Stiles, H. R., Peterson, W. H., and Fred, E. B. A rapid method for the determination of sugar in bacterial cultures. Jour. Bact., 12 : 427–439. 1926.
6. Wilson, P. W., Wenck, P., and Peterson, W. H. A statistical study of nitrogen fixation by clover plants. Soil Science, 35: 123–143. 1933.
7. ——————. Carbohydrate-nitrogen relationship in symbiotic nitrogen fixation. (In press.)

THE EFFECT OF CERTAIN FERTILIZER MATERIALS ON THE IODINE CONTENT OF IMPORTANT FOODS[1]

J. S. McHargue, D. W. Young, and R. K. Calfee[2]

IODINE is one of the less common non-metallic elements that is widely distributed in very small quantities in nature. Apparently, iodine is less abundant in its occurrence in nature than either bromine, chlorine, or fluorine; however, it has a very important physiological function in the metabolism of animals.

According to the literature, the ancient peoples of several countries had learned that certain marine plants and the tissues of some animals possessed curative properties in the treatment of goiter. After the discovery of iodine by Courtois (1)[3] in 1811, these substances were shown to contain considerable quantities of iodine. For example, the Chinese (2) are said to have burned seaweeds and sponges and fed the ash to persons afflicted with goiter about 3,500 years before the discovery of iodine. The early Greeks and Romans (2) are also said to have fed the thyroid gland from sheep and goats to patients afflicted with goiter.

In 1820, Coindet (3), a physician at Geneva, painted the throats of goiter patients with a tincture of iodine and observed that a few of them were apparently benefited while others were not.

In 1850, Chatin (4) pointed out that apparently goiter was more prevalent in certain areas of soil in France which contained the smallest amount of iodine. Soils deficient in iodine have been shown, in recent years, to occur in several other parts of the world.

In 1895, Baumann (5) discovered that iodine is concentrated in the thyroid gland and that this organ contains several times more of the element than any other tissue examined in the animal body. This discovery set a host of investigators to work in all civilized countries to ascertain the significance of the accumulation of iodine in the thyroid gland. It was not until 1915, however, that Kendall (6) succeeded in isolating the hormone, thyroxine, from the thyroid gland and proved that the pure substance contained 65% iodine. Other investigators have further proved that thyroxine performs a very important function in the metabolism of animals and that iodine is indispensable in the economy of both plants and animals.

Von Fellenberg and other investigators (7) estimate that the iodine requirement for an adult person is about 0.000014 gram per day. It is the consensus of opinion among investigators in this field

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[3] Figures in parenthesis refer to "Literature Cited," p. 565.

that the higher forms of animals can assimilate organic combinations of iodine better than the inorganic forms of this element. Accordingly, the question of whether or not normal foods contain an adequate amount of iodine is one of fundamental importance in the art of agriculture.

Certain crude forms of fertilizer materials which occur in nature have been shown to contain a considerable quantity of iodine. For some time an investigation concerning the iodine content of certain fertilizer materials, limestone rocks, soils, forage crops, and foods produced in various parts of Kentucky has been under way at the Kentucky Agricultural Experiment Station. Some of the results thus far obtained at our laboratory and elsewhere are shown in the following tables, the results being the averages of two or more closely agreeing determinations. Table 1 shows the iodine content of various fertilizer materials.

TABLE 1.—*Iodine content of various kinds of fertilizer materials.*

Fertilizer material	Iodine content in p.p.b.	
	Minimum	Maximum
Superphosphate	104	5,700
Potassium sulfate	0	120
Potassium chloride	60	160
Basic slag	0	360
Ammonium sulfate	0	400
Limestone rocks	200	7,000
Rock phosphate (crude)	5,700	20,000
Chile nitrate (crude)	11,000	149,200
Stable manure*	——	1,000
Turnip manure*	——	5,400
Island phosphate*	——	4,200
Guano*	24,000	26,400

*Reported by Orr and Leitch (8).

The above results show that the iodine content of some fertilizers may vary widely. However, crude Chile nitrate and raw rock phosphate contain relatively large amounts of the element and afford all the iodine necessary for the growth of plants and the production of foods on soils deficient in this element.

TABLE 2.—*Summary of iodine content of Kentucky soil.*

Areas	No. of samples analyzed	Iodine in p.p.m.		
		Maximum	Minimum	Average
1. Purchase	42	6.93	1.59	4.57
2. W. Coal Field	69	7.37	2.31	4.11
3. Mississippian	100	16.95	2.53	6.10
4. O. Bluegrass	132	11.85	1.10	4.07
5. I. Bluegrass	64	8.25	2.40	4.35
6. E. Coal Field	14	3.08	0.80	2.05
Total	421	16.95	0.81	4.59

Six principal geological areas occur in Kentucky. Soils from each of these areas were analyzed by the combustion method for iodine. A summary of the results is shown in Table 2 (9).

It will be observed from the results in Table 2 that the soils in area 6, the Eastern Coal Fields, contained the smallest amount of iodine, therefore the iodine content of foods produced in this part of the state is of particular interest in connection with iodine study. Accordingly, samples of corn produced in several different counties of the Eastern Coal Field were obtained and analyzed for iodine. The results are shown in Table 3.

TABLE 3.—*Iodine in corn grown in 19 counties in eastern Kentucky, 1933.*

County	Fertilizer treatment	Yield, bu. per acre	Iodine content in p.p.b.
Boyd	Rich land+manure	54	68
Knox	———?	—?	87
Bell	200 lbs. superphosphate	72	88
Madison	———?	30	88
Johnson	———?	30	90
Rockcastle	———?	80	103
Whitley	Manure+superphosphate	52	109
Powell	Limestone+superphosphate	65	111
Jackson	Limestone+200 lbs. 2-12-2 fert.	80	120
Breathitt	———?	—?	120
Magoffin	Manure	135	123
Elliott	Manure	79	132
Letcher	300 lbs. superphosphate	50	180
Clay	Limestone+superphosphate	80	200
Laurel	Limestone+superphosphate	56	212
Lee	Manure	55	220
Leslie	———?	—?	586
Morgan	3-8-6 fertilizer	60	720
Menifee	———?	—?	250,000

The bluegrass soils upon which were grown the samples of corn shown in Table 4 are derived from the disintegration of limestone rocks and some of them are rich in phosphorus. However, the iodine

TABLE 4.—*Iodine content of corn produced on untreated bluegrass soils in 1934.*

Soil No.	Iodine content in p.p.b.
Bourbon County	
1	720
2	423
3	480
4	483
Fayette County	
1	144
2	132
3	176
4	189
5	151
6	144
7	206
Garrard County	
1	1,750

content of the corn apparently was not affected very much by soils that contained relatively large amounts of phosphorus.

In the first 12 samples given in Table 3, the iodine content averages 103 p.p.b. It may be assumed that where fertilizers were used on these 12 samples they contained relatively small amounts of iodine. Apparently corn that contains 100 p.p.b. of iodine or less is to be regarded as deficient in this element. The average yield for 10 of the first 12 counties was 67.7 bu. per acre.

Samples of corn from the next four counties gave an average of 203 p.p.b. of iodine and the average yield for these counties was 60.2 bu. Apparently, the iodine content of these four samples of corn was affected appreciably by the fertilizers used.

The samples of corn from the next two counties, Leslie and Morgan, have an average iodine content of more than 6 times the average of the first 12 samples and more than 3 times the average of the next four samples. Accordingly, the iodine content of the samples of corn from Leslie and Morgan counties was also affected by fertilizer treatment.

The sample from Menifee County is of unusual interest because of the very large amount of iodine it contained. This corn was reported to have been grown by a member of a 4-H Club and thus far we have not succeeded in obtaining information as to what kind and how much fertilizer was used in producing it. However, for the present discussion, we are assuming that a fertilizer containing considerable iodine, either sodium nitrate or rock phosphate, or both, was used in growing this corn. The sample received consisted of approximately 5 pounds of apparently normal grains of yellow corn. Previous to the analysis of this sample, it had not occurred to us that it would be possible to increase the iodine content of corn to such a high level. Expressed in per cent, this corn contained 0.025% iodine, or approximately 1/10 as much iodine as is contained in seaweeds. An average size grain of Reed's Yellow Dent field corn weighs approximately 0.4 gram. Assuming that the average person requires 0.000014 gram of iodine per day, as stated by von Fellenberg, one grain of the sample of corn from Menifee County, if divided into 7 equal parts, would supply as many adult persons with their daily iodine requirement.

Plants absorb inorganic salts and synthesize organic combinations from them. It occurred to us that possibly the corn plants, in this case, might have absorbed a relatively large amount of an inorganic iodine compound and stored it in the seed unchanged. However, tests by dialysis with water and alcohol proved that the iodine was in organic combination and therefore in the proper form for assimilation when used as food for animals. Other tests by which different protein fractions were separated showed that iodine was in combination with all of the fractions thus separated. The fat, protein, and ash content of the high-iodine corn were normal. Furthermore, this sample of corn indicates a way of producing an edible food high in iodine organically combined for livestock and man.

Thru the cooperation of the Agronomy Department of the Experiment Station, we were able to obtain 18 samples of wheat grown in

1932 with various fertilizer treatments at the Fariston Experiment Field, located in the southeastern part of the state. The results for iodine in these samples of wheat are shown in Table 5.

TABLE 5.—*Iodine content of 18 samples of wheat produced on the same field but with different fertilizer treatments, composite samples.*

No. of sample	Treatment	Iodine in p.p.b.
C-812	Check plats	425
C-813	Manure	392
C-814	Rock phosphate + finely ground limestone	700
C-815	Manure + rock phosphate + finely ground limestone	773
C-816	Rock phosphate	720
C-817	Manure + rock phosphate	580
C-818	Superphosphate	615
C-819	Nitrogen + superphosphate	525
C-820	Phosphorus + potassium	690
C-821	Manure + phosphorus + potassium	425
C-822	Phosphorus + potassium + nitrogen	1,330
C-823	Manure + phosphorus + potassium + nitrogen	450
C-824	Limestone + superphosphate	375
C-825	Nitrogen + limestone + superphosphate	450
C-826	Limestone + rock phosphate	790
C-827	Manure + limestone + rock phosphate	500
C-828	Phosphorus + potassium + nitrogen	676
C-829	Manure + phosphorus + potassium + nitrogen	755

The iodine content of the check sample was 425 p.p.b., the maximum 1,330 p.p.b., and the average of the 17 treated samples, 620 p.p.b. These results show a rather wide variation in the iodine content of wheat grown on the same field and suggest that the differences are due to variation in the iodine content of the fertilizers used.

During the summer of 1934 an experiment was carried on in which varying quantities of potassium iodide were added to the soil on which corn plants were grown. At different times during the growing season and at maturity the plants or the grain produced were analyzed for iodine. The results of the different treatments are given in Table 6.

TABLE 6.—*Iodine content of corn grown in soil to which increasing amounts of potassium iodide were added during the growing season.*

Material	No.	Iodine added per plant, grams	Iodine found in p.p.b.
		June 20, 1934	
Young plants	1	0.10	12,000
Young plants	2	0.18	15,000
Young plants	3	0.27	28,000
Young plants	4	0.36	33,000
Young plants	5	0.90	34,000
		July 27, 1934	
Young leaves	1	0.27	20,000
Young leaves	2	0.54	13,000
Young leaves	3	0.81	30,000
Young leaves	4	1.08	10,000
Young leaves	5	2.70	34,000

TABLE 6.—*Continued.*

Material	No.	Iodine added per plant, grams	Iodine found in p.p.b.
		Aug. 17, 1934	
Leaves	1 White	0.33	4,000
Leaves	2 White	0.66	6,000
Leaves	3 White	0.99	10,000
Leaves	4 White	1.32	14,000
Leaves	5 White	3.30	26,000
Leaves	1 Yellow	0.33	4,000
Leaves	2 Yellow	0.66	6,000
Leaves	3 Yellow	0.99	10,000
Leaves	4 Yellow	1.32	6,800
Leaves	5 Yellow	3.30	11,000
Grain	1 White	0.33	2,000
Grain	2 White	0.66	7,000
Grain	3 White	0.99	11,000
Grain	4 White	1.32	11,000
Grain	5 White	3.30	24,000
Grain	1 Yellow	0.33	2,000
Grain	2 Yellow	0.66	6,000
Grain	3 Yellow	0.99	11,000
Grain	4 Yellow	1.32	15,000
Grain	5 Yellow	3.30	25,000
Stalk	1 White	0.33	4,000
Stalk	2 White	0.66	5,000
Stalk	3 White	0.99	6,000
Stalk	4 White	1.32	11,000
Stalk	5 White	3.30	14,000
Stalk	1 Yellow	0.33	3,000
Stalk	2 Yellow	0.66	5,000
Stalk	3 Yellow	0.99	11,000
Stalk	4 Yellow	1.32	10,000
Stalk	5 Yellow	3.30	18,000
		Nov. 5, 1934	
Grain	1 White	0.42	310
Grain	2 White	0.84	416
Grain	3 White	1.26	670
Grain	4 White	1.68	880
Grain	5 White	4.20	2,700
Grain	1 Yellow	0.42	400
Grain	2 Yellow	0.84	570
Grain	3 Yellow	1.26	760
Grain	4 Yellow	1.68	1,200
Grain	5 Yellow	4.20	2,400
Exp. Sta. Farm grain	White	Untreated	178
Exp. Sta. Farm grain	Yellow	Untreated	192

SUMMARY

1. Crude Chile nitrate, raw rock phosphate, and limestone rocks may contain enough iodine to influence the iodine content of forage crops and vegetables when applied in adequate amounts to soils deficient in iodine.

2. Plants may absorb relatively large amounts of iodine without producing any signs of toxicity.

TABLE 7.—*Iodine content of vegetables.*

Kind of vegetable	Check plat, iodine in p.p.m.	Treated vegetables, iodine in p.p.m.	Ratio of increase
Beet tops	0.6	237	395
Cabbage	0.5	280	560
Lettuce	0.4	91	228
Onion bulbs	—	400	—
Onion tops	—	800	—
Pumpkin	0.2	10	50
Spinach	3.2	532	166
Tomato (fruit)	0.2	30	150

3. It is a simple matter to increase the iodine content of forage crops and vegetables by adding appropriate amounts of potassium iodide to the soil in which they are grown.

4. Tests by dialyses and the separation of various protein fractions of a sample of corn that contained a relatively large amount of iodine showed that this element was present in organic combinations and therefore in suitable form for assimilation by livestock and man.

LITERATURE CITED

1. COURTOIS, BERNARD. Ann. de Chemie., 1 : 88. 1813.
2. CHEMICAL FOUNDATION. Chemistry in Medicine. New York. 1928. (Page 286.)
3. ————————. Chemistry in Medicine. New York. 1928. (Page 287.)
4. CHATIN, A. Researches upon iodine in the air, water, soils, and alimentary products of the Alps of France and of Piedmont. Compt. Rend, Acad. d. Sci., 33 : 529. 1850.
5. BAUMANN, EUGENE. Uber das normal vorkommen von Jod in Thierkoerper, Ztschr. f. physiol. Chem., 21 : 319. 1895.
6. KENDALL, E. C. Isolation of the iodine compound which occurs in the thyroid. Jour. Biol. Chem., 39 : 125. 1919.
7. ORR, J. B., and LEITCH, I. Iodine in Nutrition. London: Medical Research Council. 1929. (Page 82.)
8. ————————, ————————. Iodine in Nutrition. London: Medical Research Council. 1929. (Page 14.)
9. MCHARGUE, J. S., and YOUNG, D. W. The iodine content of the soil in Kentucky. Soil Science, 35 : 425. 1933.

THE KILLING EFFECT OF HEAT AND DROUGHT ON BUFFALO GRASS AND BLUE GRAMA GRASS AT HAYS, KANSAS[1]

D. A. Savage and L. A. Jacobson[2]

THE short grasses, buffalo grass (*Buchloe dactyloides* (Nutt.) Engelm.) and blue grama grass (*Bouteloua gracilis* (H. B. K.) Lag.), are considered very drought resistant and fully adapted to the driest sections of the central Great Plains where they constitute the principal native vegetation. This has been expressed or implied by numerous investigators, including Lyon and Hitchcock (7)[3], Shantz and Zon (13), Shantz (12), Aldous and Shantz (1), and Savage (9, 10). Shantz (11) reported that "the principal adaptation of these short grasses to arid conditions lies in their ability to dry out (become dormant) and to revive quickly when water is again supplied."

Other drought-enduring characters of these grasses include extensive fine-branched root systems, agressive low-growing aerial parts, and the ability of the leaf blades, as shown by Weaver and Fitzpatrick (16), to limit transpiration by rolling tightly during periods of stress. In reference to the prairie grasses of eastern Nebraska, Weaver and Himmel (18) stated that "a few relics of the drier climates, e. g., *Bouteloua gracilis* and *B. hirsuta* withstood the drought (of 1930) best." Sarvis (8) reported that dry seasons were no doubt responsible for a reduction in the size of mats of *B. gracilis* at Mandan, N. D.

Although reports have been made by Weaver and Harmon (17) and by Wilkins (19) on the killing effect of drought on *Poa pratensis*, and by Gates (4) on other classes of vegetation, the writers found no published information to indicate that the short grasses of the plains were ever fatally injured by drought. It became apparent, however, that many of the short-grass plants in the vicinity of Hays, Kans., had been damaged beyond recovery by the record-breaking heat and drought of 1933-34.

In order to determine the local extent of the injury under different systems of grazing and lawn management, an investigation was conducted on the Fort Hays (Kansas) Branch Experiment Station in the fall of 1934. A summary of climatic conditions prevailing during the drought period is essential to a clear understanding of the problems involved in this study.

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[1] Contribution from the Fort Hays Branch of the Kansas Agricultural Experiment Station, Hays, Kans., and the Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, cooperating.

[2] Assistant Agronomist and Agent, respectively, Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture; in direct charge and assistant, respectively, of forage crops experiments at the Fort Hays Branch Experiment Station, Hays, Kans. The writers are indebted for assistance rendered in the preparation of this paper by their colleagues in the Bureau of Plant Industry and the Kansas Agricultural Experiment Station and others, particularly Prof. F. W. Albertson and Dr. A. W. Barton of the Fort Hays Kansas State College.

[3] Figures in parenthesis refer to "Literature Cited," p. 582.

CLIMATIC CONDITIONS

The 1933–34 biennium was the hottest and driest on record at Hays, Kans., since 1894–95, Table 1. A nearly continuous period of intensive drought, interspersed at wide intervals by generally ineffective light or torrential showers and characterized by high temperatures, hot winds, and excessive evaporation during the growing seasons, prevailed in this locality from October 21, 1932, to August 30, 1934. Daily precipitations have been recorded here since 1868; daily air temperatures since 1893; daily evaporations from a free-water surface for the growing seasons since 1907; and daily wind velocities for the growing seasons since 1908[4].

Precipitation.—The annual precipitation was 16.26 inches in 1933 and 16.06 inches in 1934, as compared with an average of 22.88 inches for the 67-year period, 1868 to 1934. The precipitation for the last 2 months of 1932, the first 11 months of 1933, and 9 months in 1934 was below the average.

Temperatures.—Each of the last two summers was the hottest on record in this locality. The average maximum air temperature for the six-month period, April to September, was 86.1° F in 1933 and 88.6° in 1934, as compared with a 42-year average of 82.8°. In 1934 the average maximum and mean temperatures for May, June, and July were the highest ever recorded here, and those for August were the second highest. The June temperatures in 1933 were exceeded only by those for the same month in 1934. During the latter year the daily air temperatures exceeded 100 degrees on 4 days in May, 10 days in June, 24 days in July, and 15 days in August, reaching a 42-year maximum of 117 degrees in July.

Evaporation.—As mentioned by Weaver and Himmel (18) and Hursh and Haasis (6), "the rate at which water evaporates integrates and shows quantitatively" the combined effect of various climatic factors. The highest evaporation recorded here for the growing season, April to September, inclusive, was that of 66.024 inches in 1934, which may be compared with 56.453 inches in 1933 and 47.683 inches as the average for 28 years. With the exception of August, 1933, and September, 1934, the total evaporation for every month of the growing season during the last two years was decidedly above average. In 1934 the monthly evaporation for May and July exceeded all previous extremes for those months.

Wind velocity.—The wind movement was not unduly high in 1933 but was decidedly above the 27-year average in May, June, and August of 1934.

Frost-free period.—For the 43-year period ending with 1934, the average dates of the last killing frost in the spring and the first in the fall were April 29 and October 13, respectively, which represent an average growing season of 167 days. In 1934 the first killing frost in the fall occurred on October 28. This enabled grasses revived by rather substantial rains in late summer to continue growth until that date.

LOCATION OF INVESTIGATIONS

Locations selected for quadrat studies of the drought effect included: (a) A closely grazed and severely tramped area, (b) a moderately grazed area, (c) dry land lawns, (d) lightly watered lawns, and (e) heavily watered lawns. The pastures are illustrated in Fig. 1 and the lawns in Fig. 2. Both pasture areas were grazed moderately before the drought, but area (a) was grazed closely during the

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[4] The writers are indebted to the U. S. Weather Bureau and the Division of Dry Land Agriculture, U. S. Dept. of Agriculture, for providing the basic climatic records from which these summaries were made, and to A. L. Hallsted of the latter agency, who has kept these records since 1908.

TABLE 1.—*Summary of climatological observations at the Fort Hays (Kansas) Branch Experiment Station for 1933 and 1934, compared with averages or totals for the 67-year period, 1868 to 1934.*

Years or period	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Seasonal, Apr. 1 to Sept. 30	Annual
Precipitation in Inches														
For 1933	0.07	0.21	0.33	2.14	2.82	1.07	2.12	2.73	2.03	0.03	0.54	2.17	12.91	16.26
For 1934	0.29	1.16	0.45	0.37	1.55	5.15	0.54	2.78	2.48	0.52	0.75	0.02	12.87	16.06
Av. 1868 to 1934	0.49	0.82	1.00	2.29	3.22	3.45	3.22	3.03	2.30	1.48	0.83	0.75	17.51	22.88
Evaporation in Inches from a Free-water Surface														
For 1933	—	—	—	6.850	6.990	12.875	12.442	8.896	8.400	—	—	—	56.453	—
For 1934	—	—	—	6.912	10.740	12.645	16.322	12.824	6.581	—	—	—	66.024	—
Av. 1907 to 1934	—	—	—	5.751	6.845	8.395	10.139	9.235	7.318	—	—	—	47.683	—
Wind Velocity in Miles per Hour														
For 1933	—	—	—	9.6	8.6	8.3	6.8	6.6	7.8	—	—	—	8.0	—
For 1934	—	—	—	9.1	10.1	9.8	10.0	8.3	9.8	—	—	—	9.5	—
Av. 1908 to 1934	—	—	—	10.2	8.8	7.7	6.9	6.6	7.6	—	—	—	8.0	—

Air Temperatures in Degrees, F

Absolute maximum:														
For 1933	67	71	82	87	96	112	113	108	101	85	93	74	113	113
For 1934	70	72	82	91	103	105	117	112	99	99	83	56	117	117
For 1893 to 1932	78	84	97	99	104	114	110	110	111	98	87	78	114	114
Absolute minumim:														
For 1933	11	—23	11	19	36	51	52	55	37	26	18	6	19	—23
For 1934	9	— 6	5	23	40	52	52	48	32	25	22	3	23	— 6
For 1893 to 1932	—23	—24	—10	2	17	31	37	36	20	9	—6	—21	2	—24
Average maximum:														
For 1933	54.6	46.3	62.2	66.3	77.3	97.2	96.3	90.4	89.0	73.6	62.0	53.1	86.1	72.4
For 1934	49.3	48.0	59.6	71.6	85.5	94.7	103.6	97.1	78.8	77.4	59.4	43.2	88.6	72.4
Av. 1893–1934	42.5	46.4	57.2	67.6	75.7	86.0	92.5	91.5	83.5	71.2	56.2	44.4	82.8	67.9
Average minimum:														
For 1933	21.1	12.5	31.3	40.9	49.2	64.3	66.7	63.9	59.1	41.3	30.3	24.4	57.4	42.1
For 1934	23.0	21.2	26.1	39.8	55.1	65.3	70.6	67.5	51.1	46.2	33.3	20.3	58.2	43.3
Av. 1893–1934	16.5	18.2	27.0	38.3	48.9	59.0	64.1	62.7	54.1	40.7	27.5	18.3	54.5	39.6
Mean:														
For 1933	37.9	29.4	46.8	53.6	63.3	80.8	81.5	77.2	74.1	57.5	46.2	38.8	71.8	57.3
For 1934	36.2	34.6	42.8	55.7	70.3	80.0	87.1	82.3	65.0	61.8	46.4	31.8	73.4	57.8
Av. 1893–1934	29.8	32.2	42.1	53.0	62.3	72.5	78.4	77.1	68.8	56.0	41.8	31.6	68.7	53.8

Killing Frosts

	Last in spring	First in fall	Frost-free period, days
For 1933	Apr. 16	Oct. 8	175
For 1934	Apr. 13	Oct. 28	198
Av. 1892 to 1934	Apr. 29	Oct. 13	167

drought and was subjected to severe tramping by livestock. This area, therefore, is considered to be comparable with many continuously overgrazed pastures in this vicinity. The lawns represented a part of the station campus which was clipped periodically with a mowing machine and was not watered previous to the

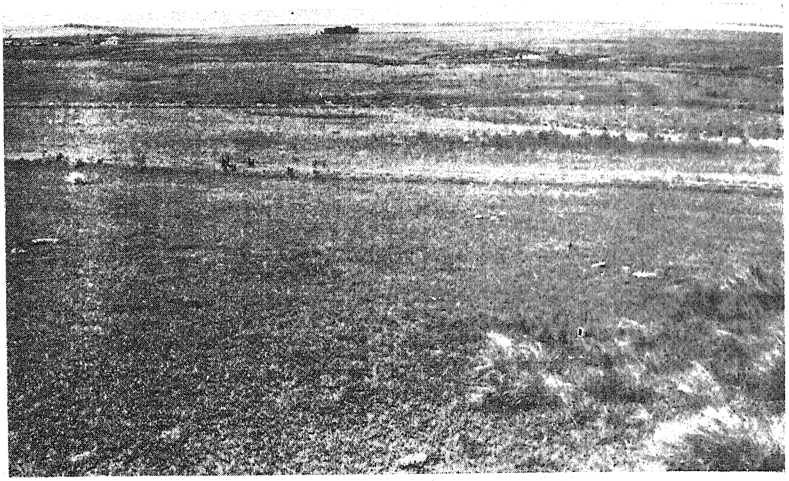

FIG. 1.—A moderately grazed native short-grass pasture on the Fort Hays Branch Station, showing typical mixtures of wire grass in the foreground and *Psoralea tenuiflora* in the background. The surface growth of the latter breaks off and blows away in late summer, leaving a smooth expanse of short grass broken at intervals by tufts of wire grass. Photographed at Hays, Kans., July 10, 1934.

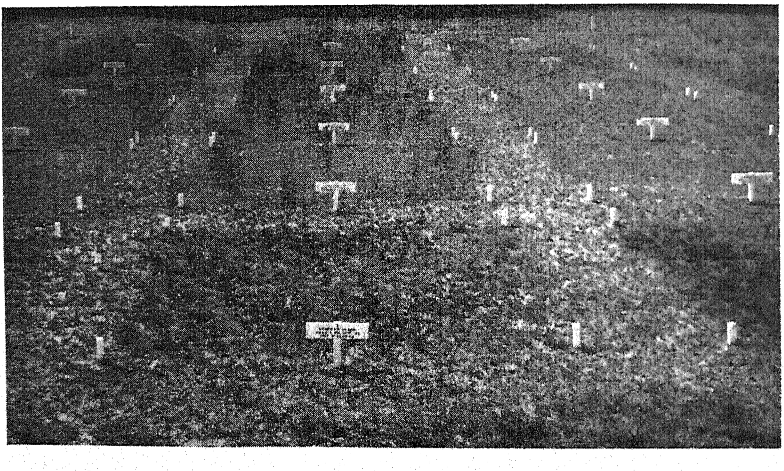

FIG. 2.—Eighteen lawn plats of native short grass clipped at varying heights and at different times in 1934. Plats in the foreground and in the right row are not watered, while those in the left row are watered heavily and in the middle row, lightly. Photographed at Hays, Kan., September 5, 1934.

drought. Beginning in the spring of 1934, 18 lawn plats were laid out and clipped continuously at different heights with lawn mowers. Some of them were watered heavily, some lightly, and some received no water.

Although the mixed prairie grasses are present to some extent in this region, the principal native pasture vegetation consists of the typical short-grass associes with scattering mixtures of other vegetation, including *Psoralea tenuiflora*, *Aristida purpurea*, and *Andropogon scoparius*. General observations before the drought indicated that the areas selected for study were almost completely occupied by buffalo grass and blue grama grass. The former appeared to predominate on grazed and other clipped areas. The stoloniferous habit of this species may account for the large basal cover noted.

APPEARANCE OF GRASS IN THE FALL OF 1934

All short-grass pastures and lawns in the immediate vicinity of Hays, Kans., assumed a bright green color in the fall of 1934, after 2.20 inches of rain were received from August 31 to September 3, followed by additional showers totaling 1.33 inches during the remainder of September, and 0.52 of an inch before frost occurred in October. Temperatures and evaporation in September were low compared with extremes for the previous months and represented conditions especially favorable for the growth of grasses. Casual observation indicated that the grass had survived the drought fairly well. Numerous weed seedlings and other growth masked the injured areas and contributed to the general green appearance as viewed from a distance. These included *Hordeum pusillum*, *Allium nuttallii*, *Sporobolus cryptandrus*, *Carex heliophila*, and *Cymopterus acaulis*. Close and repeated inspection, however, showed that an alarming number of the short-grass plants had failed to revive. Overgrazed and severely tramped pastures appeared to have suffered the most, although numerous dead plants were apparent on moderately grazed pastures and dry land lawns. Much local concern was expressed over this unprecedented condition, which prompted the inauguration of careful studies to ascertain the extent of the damage.

Before measuring the injured areas it was considered important to determine as accurately as possible if the unrevived plants were actually dead or merely in an unusually advanced stage of dormancy. The aerial portions of the apparently dead plants had every appearance of being dead. Large areas of the sod were transferred to a green house where the plants judged to be dead failed to revive, while those known to be alive grew vigorously. The live buffalo grass plants in the field produced many new stolons, ranging in length from 4 to 17 inches, before the first killing frost caused a cessation in growth on October 28.

Shantz (11) reported that drought-dormant plants of buffalo grass and grama grass are capable of renewing growth after the soil has been moistened to a depth of a few inches by a small shower. Observations by the senior author for a period of 6 years at Hays, Kans., substantiate this report. Although these statements and the facts mentioned above may not be positive proof that all live plants had renewed growth in the fall, the combined evidence indicates rather definitely that such was the case.

MATERIALS AND METHODS

Permanent quadrats were established and definitely marked off with a rigid slat-iron frame 1 meter square. Double holes were bored adjacent to decimeter markings on two sides of the frame. Two cross slats, similarly marked in decimeters and having holes at both ends to match those on the frame, were moved alternately on the frame to assist in outlining the areas in each decimeter strip.

Since the vegetation consisted mostly of short well-defined mats, a pantograph was used to chart the basal cover of grass in the different areas (Fig. 3). The basal cover represented the amount of ground surface actually covered by the nearly pure stands of short grass after most of the foliage had been removed by the grazing or clipping treatments. The short foliage cover present made it possible to delimit the matted areas with considerable accuracy. This foliage, however, doubtless caused the results to show somewhat larger coverage than would have been obtained if all of the surface vegetation had been removed, thus exposing the surface limits of growth to more precise charting. The interlacing net-work of buffalo grass stolons was considered a part of the basal cover.

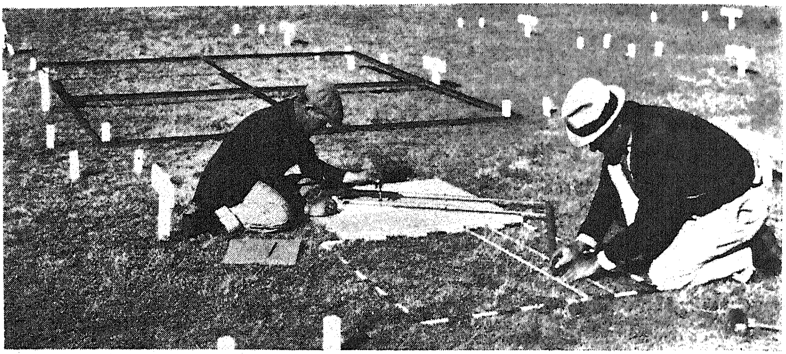

FIG. 3.—Illustrating the pantograph method of charting native short grass on a lawn plat clipped 2 inches high and watered heavily in 1934. Note the cross-wired, list quadrat frame in the background. Photographed on the Fort Hays Branch Station, Hays, Kans., September 10, 1934.

Each chart was reduced to an area 1/25th that of a square meter or by a lineal ratio of 5 to 1. This reduction is less than that made by a number of investigators, including Steiger (14), and is, therefore, considered by the writers to minimize the error recognized to be present in pantograph charting.

The pantograph was constructed with certain improvements over that discussed by Hanson and Love (5). It was fastened to a drawing board which was laid on the ground adjacent to the meter frame. Errors in operation were reduced in this manner by having the pantograph resting on practically the same plane as the grass. The edges of the grass could be followed with the inch-long pointer without changing the angle between the tip of the pointer and the arm of the pantograph. This eliminated errors due to the use of a long pointer. One operator followed instructions from the man who moved the pointer, and outlined the areas on the chart by raising and lowering a pencil in a hollow tube fastened to the proper location on the pantograph. Each area of grass was properly and simultaneously designated on the chart by means of a second pencil.

In this manner, 54 meter quadrats were charted to show live short grass, dead short grass, *Aristida purpurea*, *Andropogon scoparius*, and bare ground. Twelve of the quadrats were located on closely grazed areas, 6 on moderately grazed areas, 16 on variously clipped dry land lawns, 10 on lightly watered lawns, and 10 on heavily watered lawns. During the winter the pencil sketches of each chart were inked in, cross hatched to distinguish each type of vegetation represented, and measured with a planimeter. The resultant data were computed to determine the percentage of mortality, percentage of ground cover, and other factors under consideration.

RESULTS

The information obtained from these studies is presented and interpreted with the fairly reliable assumption that all live plants had renewed growth in the fall. Statements justifying or substantiating this belief are included in the foregoing discussion. Since, unfortunately, no quadrat studies were made before the drought, the total ground cover at that time is assumed to have been practically complete. This assumption is based, not only upon superficial observations before the drought, but upon careful charting of the dead and live growth after the drought. These combined results are considered to represent the actual cover of live growth before the drought.

It is not unusual for grasses of a turf-forming or stoloniferous nature to make nearly a perfect basal cover. Shantz (11) reported that the buffalo-blue grama grass associes often "covers practically the whole surface of the ground". In discussing the results of unpublished data obtained at Beltsville, Md., and Kylertown, Pa., Vinall (15) stated that "with the stoloniferous grasses, it is entirely possible here in the East to obtain a coverage of 95 to 100% as you do in the range areas with buffalo grass and grama grass".

Table 2 gives the average percentages of short-grass plants killed by the heat and drought of 1933–34 on local pastures and dry land lawns in comparison with the percentage of dead plants on lawns watered only in 1934. The average mortality was 74.8% on closely grazed and heavily tramped areas (Fig. 4), 64.6% on moderately grazed areas (Fig. 5), and 44.4% on dry land lawns (Fig. 6).

DROUGHT EFFECTS AGGRAVATED BY GRAZING

The high death rate on ungrazed lawns indicates that climatic conditions were primarily responsible for the mortality on all areas. The results show, however, that close grazing and tramping were indirectly accountable for the death of many plants. Under ordinary conditions the short grasses may be grazed closer and with less injury than practically any other class of vegetation. Shantz (11) stated that "ordinary grazing does not appreciably modify but somewhat favors the development of pure short-grass cover". In discussing results now being assembled for publication, Mathews[5] reports that "vegetation of the (short-grass) type prevailing in pastures at Ardmore, S. D. is not likely to be damaged without being grazed so closely that the animals grazing it suffer severe losses in weight". Hansen and Love (5) found that "buffalo grass may be favored under continuous grazing" and that "overgrazed wheat grass is replaced by blue grama grass" in Colorado.

The results here reported for Hays, Kans., indicate, however, that there is danger of heavy plant mortality occurring when short-grass

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[5] Associate Agronomist, Division of Dry Land Agriculture, Bureau of Plant Industry, U. S. Dept. of Agriculture.

pastures are grazed either moderately or intensively during prolonged periods of intense heat and drought.

TABLE 2.—*Average mortality of native grasses (buffalo and blue grama) during the heat and drought of 1933–34 on pastures and dry land lawns, compared with the percentage of dead plants on lawns watered only in 1934.*

Grazing and clipping treatment	No. of quadrats represented in averages	Average percentage of original short-grass cover		
		Killed by the drought of 1933–34	Dead plants after watering only in 1934	Difference due to watering only in 1934*
		Pastures		
Closely grazed and heavily tramped	12	74.8	—	—
Moderately grazed and lightly tramped	6	64.6	—	—
		Dry Land Lawns		
Clipped ½ in. in 1934	2	42.1	—	—
Clipped 1¼ in. in 1934	8	44.3	—	—
Clipped 2 in. in 1934	2	52.7	—	—
Cut twice 1¼ in. in 1934	2	48.3	—	—
Not cut in 1934	2	35.1	—	—
Grand av. dry land lawns	16	44.4	—	—
		Lightly Watered Lawns		
Clipped ½ in. in 1934	2	—	4.9	37.2
Clipped 1¼ in. in 1934	2	—	10.6	33.7
Clipped 2 in. in 1934	2	—	14.2	38.5
Cut twice 1¼ in. in 1934	2	—	25.0	23.3
Not cut in 1934	2	—	18.1	17.0
Grand av. lightly watered lawns	10	—	14.5	29.9
		Heavily Watered Lawns		
Clipped ½ in. in 1934	2	—	0.3	41.8
Clipped 1¼ in. in 1934	2	—	2.3	42.0
Clipped 2 in. in 1934	2	—	5.1	47.6
Cut twice 1¼ in. in 1934	2	—	6.7	41.6
Not cut in 1934	2	—	11.2	23.9
Grand av. heavily watered lawns	10	—	5.1	39.4

*Comparing the watered lawns with the dry land lawns similarly clipped.

EFFECTS OF WATERING DURING THE DROUGHT

Repeated applications of water in 1934 were decidedly beneficial in overcoming the effects of the drought of 1933 and in counteracting similar conditions in 1934. Ten quadrats on five lightly watered and variously clipped lawns showed that an average of 14.5% of the short grasses failed to survive (Fig. 7). A like number of quadrats on heavily watered and similarly clipped plats revealed an average of 5.1% dead plants at the end of the 1934 season (Fig. 8). The former plats received nine applications of water, or a total of 7.2 inches per plat, during the season. This was sufficient to keep the grass green throughout most of the ordinary growing period. The heavily watered plats received approximately twice as much water at each application, or a total of 15.6 inches per plat. The water was measured with a standard water meter and every plat in each watering treatment received the same amount at each application.

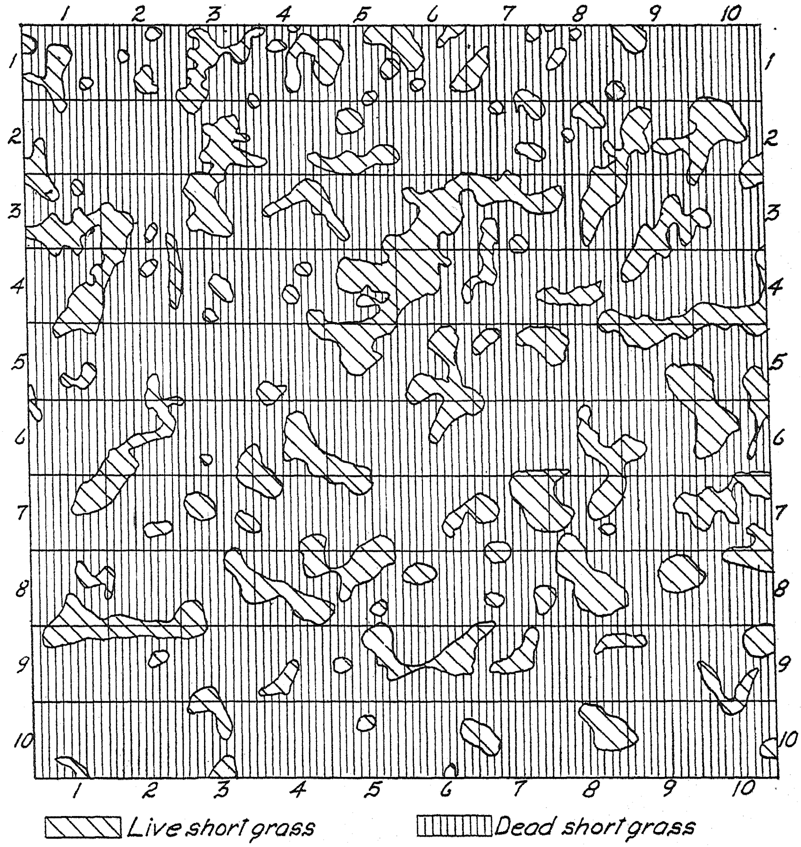

FIG. 4.—Meter quadrat No. 40 in a closely grazed area, showing 77.7% of the short-grass plants killed by heat and drought.

Late in the fall the soil moisture content on all plats, including those receiving no water, was uniformly low. This was revealed by duplicate 1-foot samples taken in November to a depth of 10 feet. These results indicate that water was not applied in excess of the needs of the grass.

BASAL COVERAGE AS AFFECTED BY DROUGHT

The average percentages of ground surface covered by short grasses on the different grazing and lawn treatments before the drought, after the drought, and after applying water in 1934 are summarized in Table 3. The basal coverage before the drought, as computed from quadrat measurements of live and dead growth after the drought, ranged from 96.5 to 100%. The average of all quadrats was slightly more than 99%.

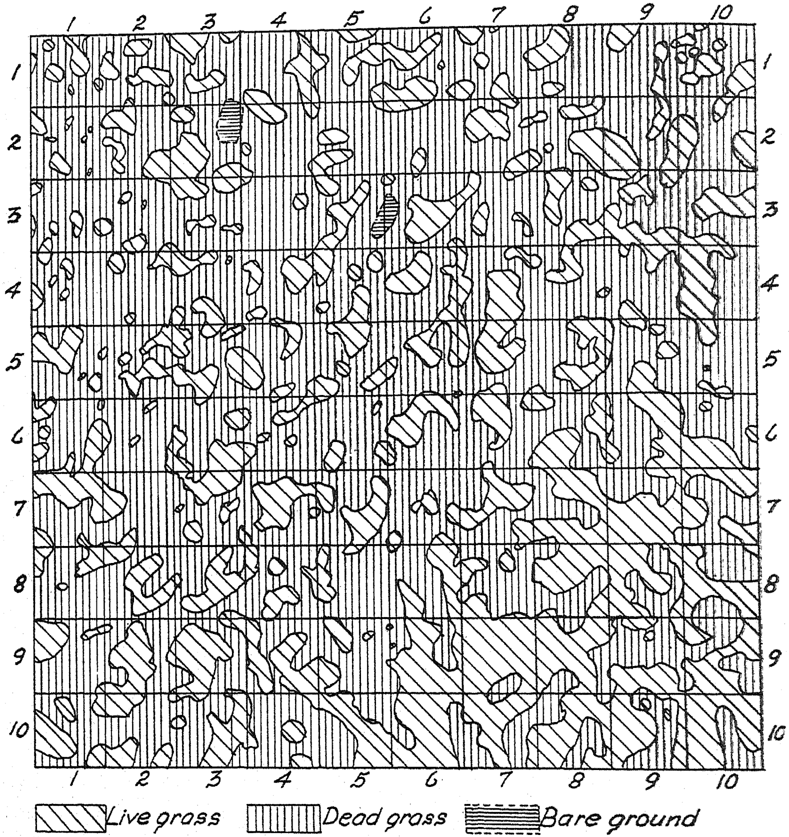

FIG. 5.—Meter quadrat No. 53 in a moderately grazed area, showing 65.6% of the short-grass plants killed by heat and drought.

After the drought the average coverage of live plants was 25.2% in the closely grazed areas, 35.4% in the moderately grazed areas, and 54.9% in the dry land lawns. The helpful effect of watering is further indicated by final basal coverages of 86.0% on the lightly watered lawns and 93.9% on the heavily watered lawns. The average difference in percentage of ground cover between the non-watered and lightly watered plats, similarly clipped, was 29.9% and the difference between the non-watered and heavily watered plats was 29.4%.

TABLE 3.—*Average ground surface covered by native short grasses (buffalo and blue grama) on pastures and lawns at the Fort Hays (Kansas) Branch Experiment Station before the drought of 1933–34, after the drought, and after applying water only in 1934.*

Grazing or clipping treatment	No. of quadrats represented in averages	Average total area covered by live short grasses			
		Before the drought of 1933–34 %	After the drought of 1933–34 %	After watering only in 1934 %	Difference due to watering only in 1934* %
		Pastures			
Closely grazed and heavily tramped	12	99.5	25.2	—	—
Moderately grazed and lightly tramped	6	99.8	35.4	—	—
		Dry Land Lawns			
Clipped ½ in. in 1934	2	96.7	56.0	—	—
Clipped 1¼ in. in 1934	8	99.6	55.4	—	—
Clipped 2 in. in 1934	2	99.1	46.9	—	—
Cut twice 1¼ in. in 1934	2	99.1	51.3	—	—
Not cut in 1934	2	99.7	64.7	—	—
Grand av. dry land lawns	16	99.1	54.9	—	—
		Lightly Watered Lawns			
Clipped ½ in. in 1934	2	99.5	—	98.4	42.4
Clipped 1¼ in. in 1934	2	100.0	—	89.5	34.1
Clipped 2 in. in 1934	2	99.3	—	85.2	38.3
Cut twice 1¼ in. in 1934	2	99.8	—	74.9	23.6
Not cut in 1934	2	100.0	—	81.9	17.2
Grand av. lightly watered lawns	10	99.7	—	86.0	31.1
		Heavily Watered Lawns			
Clipped ½ in. in 1934	2	100.0	—	99.7	43.7
Clipped 1¼ in. in 1934	2	99.8	—	97.5	42.1
Clipped 2 in. in 1934	2	97.4	—	92.5	45.6
Cut twice 1¼ in. in 1934	2	99.9	—	93.2	41.9
Not cut in 1934	2	97.8	—	86.9	22.2
Grand av. heavily watered lawns	10	99.0	—	93.9	38.8

*Comparing the watered lawns with the dry land lawns similarly clipped.

DROUGHT INJURY IN RELATION TO CLIPPING

The effects of different heights of clipping for 1 year on drought injury and basal cover are shown in the tables previously mentioned. These results support in general the findings of previous investigations by Savage (9, 10), which showed that moderate clipping to control the shading effect of tall grasses and weeds favors the spread of buffalo grass. Survival from heat and drought on all quadrats included in the averages presented increased in direct proportion to the closeness of clipping. Dry land plats clipped continuously in 1934 to maintain the growth at a height of ½ inch showed a lower percentage of dead plants and a correspondingly higher percentage of ground cover at the end of the drought than did those clipped at a height of 1¼ inches. The latter, likewise, were injured less and had more basal cover than those clipped at a height of 2 inches.

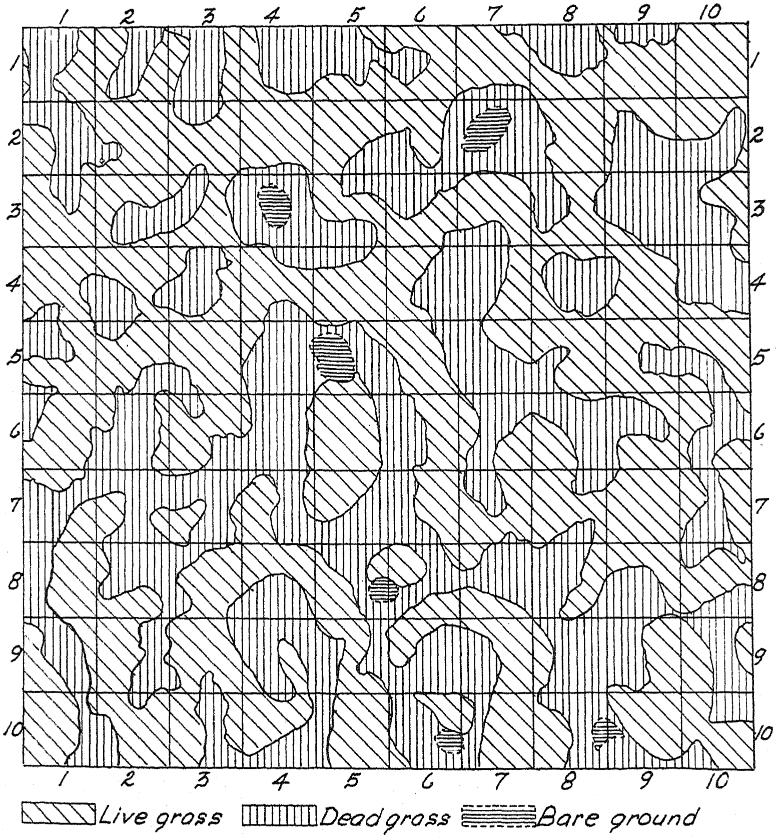

FIG. 6.—Meter quadrat No. 3 on a dry land lawn clipped 1¼ inches high in 1934, showing 43.5% of the short-grass plants killed by heat and drought.

It should be definitely understood that these results were obtained from clippings made at various heights for only 1 year. Continued close clipping may show a reduction in the spread of the plants similar to that reported by Aldous (2) for the prairie grasses of eastern Kansas. The fact that close clipping for one season was helpful while close grazing for a longer period was detrimental is partly explained by the report of Culley, Campbell, and Canfield (3) that "clipping does not simulate actual grazing."

There was a similar positive correlation between closeness of clipping and recovery due to watering. The lightly watered plats clipped at a height of ½ inch, 1¼ inches, and 2 inches showed average basal covers of 98.4%, 89.5%, and 85.2%, respectively. Heavily watered plats similarly clipped had average basal covers of 99.7% 97.5%, and 92.5%, respectively.

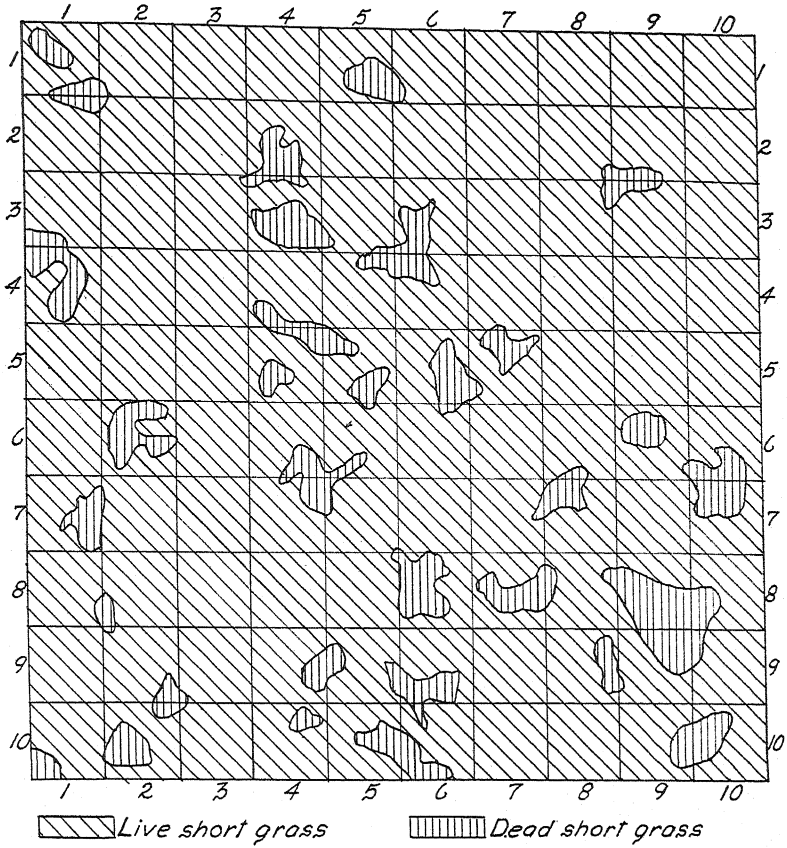

FIG. 7.—Meter quadrat No. 16 on a lawn lightly watered and clipped 1¼ inches high in 1934, showing that 11.0% of the short-grass plants were dead at the end of the drought.

SUGGESTIONS FOR PROMOTING RECOVERY

The results thus far obtained from these quadrat studies are to be used also as a basis for determining the rate and duration of recovery in the future. It is proposed to make repeated charts of the growth until recovery is completed.

Although much of the short grass in the vicinity of Hays, Kans., is shown to be dead, the remaining live plants are rather uniformly distributed and may be expected to spread rapidly under normal conditions if protected from severe damage by livestock. The vigorous growth of stolons produced during the favorable growing period of 59 days prevailing in the fall of 1934 and the recovery made under watering treatments indicate that the original stands may become re-established in a relatively short time.

Transplanting experiments at this station show that 4-inch cubes of buffalo grass sod spaced 1 foot apart on cultivated land will spread to cover the intervening spaces in one season of average rainfall, according to Savage (9, 10). The live plants in the drought-stricken areas are generally closer than 1 foot apart and, with their roots undisturbed by transplanting, should spread fast under favorable conditions.

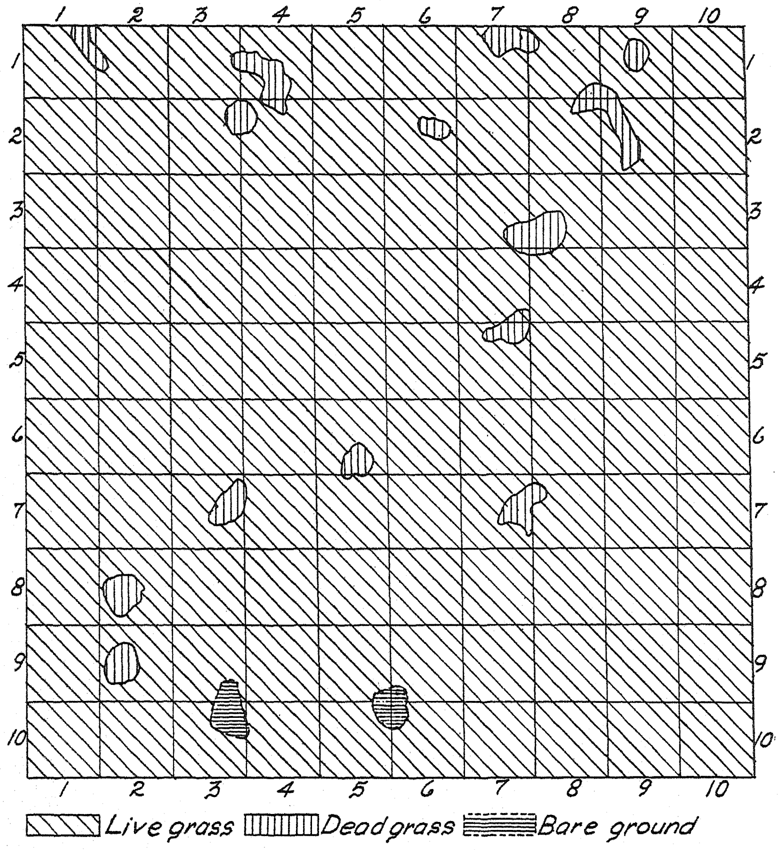

FIG. 8.—Meter quadrat No. 18 on a lawn heavily watered and clipped 1 ¼ inches high in 1934, showing that 2.9% of the short-grass plants were dead at the end of the drought.

Moderate clipping to eliminate the shading effect of taller grasses and weeds has encouraged the spread of buffalo grass in resodded areas at this station. The spread was materially retarded when the areas were neither clipped nor grazed. Considering the detrimental effects of extreme overgrazing, and of not grazing or cutting, it seems advisable to suggest that a system of deferred, moderate grazing would hasten recovery from drought. Keeping the livestock off the pastures until about June 1 will encourage the development and rooting of stolons and protect them from early damage by tramping. Thereafter, moderate grazing may keep palatable weeds under control, admit sunlight essential to the spread of short grasses, and shorten the period of recovery. It would be desirable to mow the pastures at intervals to control tall, unpalatable plants, especially during the period when grazing is deferred. Recovery would no doubt be hastened still more by excluding the livestock from the pastures until the spring of 1936, and by mowing often enough to keep the taller growth under control during the season of 1935.

SUMMARY AND CONCLUSIONS

Buffalo grass and blue grama grass are generally considered to be highly resistant to the effects of heat and drought, but in the vicinity of Hays, Kans., many plants of these grasses appear to have been injured beyond recovery by the record-breaking heat and drought of 1933-34.

According to local weather records this was the hottest and driest biennium since 1894-95. A nearly continuous and disastrous drought prevailed in this locality from October 21, 1932, to August 30, 1934.

The charting of live and dead plants in the fall of 1934 was done on typical short-grass pastures and lawns on the Fort Hays (Kansas) Branch Experiment Station. These pastures and lawns assumed a bright green color in the late summer and fall of 1934 as a result of 4.05 inches of precipitation accompanied by marked reductions in previous extremes of temperature and evaporation. Plants which did not renew their growth under these favorable natural conditions were properly assumed to be dead since a representative number of them which were transferred to the greenhouse failed to revive and since the live plants grew vigorously both in the field and in the greenhouse.

A pantograph was used to chart the basal cover of live short grass, dead short grass, other turf-forming vegetation, and bare ground on 54 meter quadrats, 12 of which were located on a closely grazed and severely tramped area, 6 on a moderately grazed area, 16 on dry land lawns clipped at various heights, 10 on lightly watered lawns, and 10 on heavily watered lawns.

The average percentage of short grasses killed by the heat and drought of 1933-34 was 74.8 on closely grazed and severely tramped areas, 64.6 on moderately grazed areas, and 44.4 on unwatered lawns. Repeated applications of water to lawns in 1934 were decidedly beneficial in overcoming the effect of the drought of 1933 and counteracting similar conditions in 1934. Only 14.5% of the short grasses failed to survive on the lightly watered lawns and only 5.1% on the heavily watered lawns.

The average basal cover of short grass on all plats before the drought was 99% as determined from measurements of the live and dead growth after the drought. The heat and drought reduced this cover to an average of 25.2% on the closely grazed areas, 35.4% on the moderately grazed areas, and 54.9% on unwatered lawns. Light watering in 1934 resulted in an average basal cover of 86.0%; heavy watering, 93.9%.

There was a direct and positive correlation between closeness of clipping for 1 year and survival from drought. A similar positive correlation occurred between closeness of clipping and recovery due to watering.

Climatic conditions were directly responsible for the injury on all areas, although close grazing and tramping contributed to the mortality of many plants.

Results obtained from soil-moisture samples indicated that water was not applied to any of the lawn plats in excess of the needs of the grass.

Although much of the short grass in local pastures is dead, the surviving plants are rather uniformly distributed and may be expected to recover rapidly under normal conditions if protected from severe damage by livestock.

LITERATURE CITED

1. ALDOUS, A. E., and SHANTZ, H. L. Types of vegetation in the semi-arid portions of the United States and their economic significance. Jour. Agr. Res., 28: 99–128. 1924.
2. ————. Effect of different clipping treatments on the yield and vigor of prairie grass vegetation. Ecol., 11: 752–759. 1930.
3. CULLEY, M. J., CAMPBELL, R. S. and CANFIELD, R. H. Value of clipped quadrats. Ecol., 14: 35–39. 1933.
4. GATES, F. C. Heat and drought effects during 1934 on vegetation in north-central Kansas. Bul. Ecol. Soc. Amer., 15 : 31. 1934.
5. HANSON, HERBERT C., and LOVE, L. DUDLEY. Comparison of methods of quadrating. Ecol., 11: 734–738. 1930.
6. HURSH, C. R., and HAASIS, F. W. Effect of 1925 summer drought on southern Appalachian hardwoods. Ecol., 12: 380–386. 1931.
7. LYON, T. L., and HITCHCOCK, A. S. Pasture, meadow, and forage crops in Nebraska, U. S. D. A., Bur. Plant Ind. Bul. 59. 1904.
8. SARVIS, J. T. Effect of different systems of grazing and intensities of grazing upon the native vegetation at the Northern Great Plains Field Station, U. S. D. A. Bul. 1170. 1923.
9. SAVAGE, D. A. Buffalo grass for fairways in the Plains states. Bul. U. S. Golf Assoc., Green Sect., 13: 144–149. 1933.
10. ————. Methods of reestablishing buffalo grass on cultivated land in the Great Plains, U. S. D. A. Circ. 328. 1934.
11. SHANTZ, H. L. Natural vegetation as an indicator of the capabilities of land for crop production in the Great Plains area. U. S. D. A. Bur. Plant Ind. Bul. 201. 1911.
12. ————. The natural vegetation of the Great Plains region. Ann. Assoc. Amer. Geographers, 13: 81–107. 1923.
13. ————, and ZON, RAPHAEL. Atlas of American Agriculture, Part I. The Physical Basis of Agriculture, Section E Natural Vegetation. U. S. D. A. Advance Sheets, 6. 1924.
14. STEIGER, T. L. Structure of prairie vegetation. Ecol., 11: 170–217. 1930.
15. VINALL, H. N. A letter informally reporting the results of unpublished data obtained by the U. S. Dept. of Agr. from grazing experiments conducted at Beltsville, Md., and Kylertown, Pa. 1935.
16. Weaver, J. E., and FITZPATRICK, T. J. The prairie. Ecol. Monographs, 4: 109–295. 1934.
17. ————, and HARMON, GEO. W. Quantity of living plant material in prairie soils in relation to run-off and soil erosion. Univ. Nebr., Cons. and Survey Div., Cons. Dept. Bul. 8. 1935.
18. ————, and HIMMEL, W. J. The environment of the prairie. Univ. Nebr., Cons. and Survey Div., Cons. Dept. Bul. 5. 1931.
19. WILKINS, F. S. Effect of overgrazing on Kentucky bluegrass under conditions of extreme drouth. Jour. Amer. Soc. Agron., 27: 159. 1935.

BOOK REVIEW

THE HOP INDUSTRY

By Herbert H. Parker. London: P. S. King & Son, Ltd. 327 pages, illus. 1934. 15 shillings, net. Import duty approx. 45 cents per copy.

THIS book is based on a recent survey on the hop industry in Great Britain, undertaken as a Ph.D. thesis subject and later published in book form under subsidy from the University of London. It deals chiefly with the history, development, and present status of the industry in the British Isles, yet merits the attention of American hop growers, agronomists, and economists, especially on the Pacific Coast where England now looks as a rule for the major portion of her foreign supplies.

The first section provides an historical background of English hop culture and a review of the literature from the introduction of hops in 1524 down to the opening of the present century. The treatment is that of the evolution of the technic of production during this period. The second section deals with present-day problems of production, and contains excerpts and citations to recent research literature in England in the fields of soil fertilization, training, drying, breeding, production costs, marketing, and diseases and pests. Chapter 4 of this section is a review of the status of the industry in the principal hop-producing countries of the world, and of the position of England in relation to continental and American trade.

Section 3 is an analysis of the various attempts which have been made in England to market hops on a collective basis and is of interest to American economists and producers. An appendix contains much statistical data under the headings historical notes, cost of production at different periods, acreage, prices, and customs duties in different countries. The work is concluded with an extensive bibliography of the field covered. (G. W. H.)

AGRONOMIC AFFAIRS

MEETING OF SOUTHERN AGRONOMISTS

THE following program has been arranged for the summer meeting of southern agronomists to be held in Virginia August 7 to 10, inclusive.

WEDNESDAY, AUGUST 7

Leaving Suffolk at eight o'clock in the morning, the group will visit the peanut and cotton station at Holland, Virginia, until 10:30; then proceed to the Truck Experiment Station near Norfolk and look over the vegetable experiments until 2:30 p.m. Thence to the forage crop experiment station near Williamsburg.

THURSDAY, AUGUST 8

Morning

Enroute to and visiting the sun-cured tobacco experiment station at Bowling Green.

Afternoon

Enroute to and visiting the general crop experiment station near Staunton.

FRIDAY, AUGUST 9

Morning

Enroute to and visiting the bright tobacco experiment station at Chatham.

Afternoon

Enroute to and visiting central experiment station at Blacksburg.

SATURDAY, AUGUST 10

Enroute to and visiting the pasture and grazing experiment station at Glade Spring.

Historic, scenic, and other points of interest along the tour include the world's largest peanut processing plants at Suffolk, Hampton Roads, restored Colonial Williamsburg, Jamestown, Yorktown, tobacco houses in Richmond, the City of Richmond, the Valley of Virginia, the University of Virginia, Natural Bridge, Appomattox, Virginia Polytechnic Institute, Mountain Lake, and Fort Chiswell on the historic Boone trail.

The tour will be preceded on Monday and Tuesday, August 5 and 6, by a meeting of the Tobacco Research Committee in Suffolk.

ANNUAL MEETING OF THE SOCIETY

THE twenty-eighth annual meeting of the Society will be held in the Stevens Hotel in Chicago on December 5 and 6, with the American Soil Survey Association beginning its sessions on December 3. These dates coincide with those for the International Livestock Show and the National Hay and Grain Show. Following the usual practice, the Society will meet as a whole in a half-day general session with special programs arranged by the Soils and Crops Sections occupying the remaining time.

PROGRAM OF THE CROPS SECTION AT CHICAGO

PROFESSOR R. D. Lewis, Chairman of the Crops Section of the Society, announces the first call for papers to be presented at the annual meeting of the Society in Chicago next December. A round table session on "Policies and Problems in the Release and Distribution of Corn Hybrids" is being arranged. Round table or panel discussion groups have been suggested for other topics. In view of the agronomic interest in forage crops, papers are suggested for such topics as Forage Crops in Relation to Soil Conservation, Breeding Hay and Pasture Plants, Pasturing of Alfalfa, Composition of Forage Crops in Relation to Animal Nutrition and Diseases, Cold and Drouth Resistance, Root Systems of Farm Crops, and Methods of Obtaining Seedings. Advances in the knowledge of chemicals in weed control may well be reported. Contributions on improved methodology ("new tricks") in agronomic research and education are especially desired.

The title, author, and time required for presentation of the paper should be sent at an early date to Professor Lewis, Department of Agronomy, Ohio State University, Columbus, Ohio. Since the program is to be completely formulated by October 15, titles should be submitted prior to October 1.

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A COMPARISON OF GLASS AND QUINHYDRONE ELECTRODES FOR DETERMINING THE pH OF SOME IOWA SOILS: III. THE CHANGE IN pH OF THE SOIL-WATER MIXTURE WITH TIME[1]

HAROLD L. DEAN AND R. H. WALKER[2]

IN previous investigations (4, 5),[3] experiments were conducted to determine the suitability of different types of glass electrodes, and to study the variability of the results obtained with glass and quinhydrone electrodes in determining the pH of soils. The study on the suitability of different types of glass electrodes showed that similar results were obtained with each of the four types employed. The modified bulb, silver-silver chloride type, however, was found most practicable for routine determinations. When the determination was made by either the glass or quinhydrone electrode, the variability in the pH of 25 replicate samples of different soils was comparatively small and presumably of little consequence. The "QH" and "QH electrode" errors were found to be only slight for the soils studied and it was concluded that with these soils the quinhydrone electrode method would give fairly reliable results when compared with those obtained with the glass electrode. The potentials of the glass and quinhydrone electrodes were found to change somewhat during the pH determination, and it was concluded that it is desirable to check the glass and quinhydrone electrodes against a known buffer solution at frequent intervals during their use.

In these earlier experiments it was also observed that the potential difference of the soil suspensions, when determined by either the glass or quinhydrone electrodes, changed somewhat with time. Although the potentials of the electrodes themselves changed slightly during the 20 minutes they were immersed in the soil suspensions, when checked against a standard buffer solution before and after immersion, this change appeared to be large enough to account for only a very small portion of the drift observed in the pH of the suspensions.

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[1] Journal Paper No. J 253 of the Iowa Agricultural Experiment Station, Ames, Iowa. Project No. 229. Received for publication March 23, 1935.

[2] Research Fellow and Research Associate Professor of Soils, respectively. The authors are indebted to Dr. P. E. Brown for the suggestions and criticisms offered in the course of this work and in the preparation of the manuscript.

[3] Figures in parenthesis refer to "Literature Cited," p. 595.

Biilman and Jensen (2), Hissink (6), Baver (1), Clark and Collins (3), Naftel (7), and others have observed a similar drift in potentials when using the quinhydrone electrode, but in most cases this drift has been attributed to the reaction of the quinhydrone with the soil constituents. This, however, would not explain the apparent drift, though it was small, observed when using the glass electrode. It seemed desirable, therefore, to determine whether there was an actual change in the pH of the soil-water mixture during the period it was under observation. The results of this study are reported in this paper.

REACTION STUDIES ON SOIL SUPERNATANT LIQUIDS

In this study five different soils were used, *viz.*, Tama silt loam, Shelby loam, Carrington loam, Grundy silt loam, and Marshall silt loam. The soils were air-dried and passed through a 20-mesh sieve. Thirty-gram samples of each soil were placed into 150-cc extraction flasks and 75 cc of CO_2-free distilled water were added to each sample. The soil-water mixture was then shaken vigorously for 1 minute and allowed to stand until the pH determinations were made. At the end of ¼, ½, 1, 3, 6, 12, and 24 hours the pH was determined on quadruplicate samples. To make the determinations in the first experiment, the supernatant liquid was poured into a specially constructed U-shaped tube, the glass electrode was then immersed in the liquid and the potential difference was measured. The methods used in making the measurements are fully described in the first paper of this series (4). After the pH determination was made with the glass electrode, quinhydrone was added to the liquid, a platinum electrode was connected with the apparatus, and the pH was again determined.

In this manner determinations of pH were made by the glass and quinhydrone electrode methods on soil samples that had been in contact with water for various periods of time.

The results of this study are shown in Table 1. In order to determine the significance of these data, a statistical analysis of variance was made as described by Snedecor (8). The results of the analysis are presented in Table 2.

It may be noted from the statistical data that the difference between means of quadruplicate samples of the different soils was not significant. This indicates that the variations in the pH of the four replicate samples of soil, when the determinations were made with the glass or quinhydrone electrode, at any one time were not statistically significant. As may be noted in Table 1, the largest difference between samples at any one period with Tama silt loam was small, being only 0.06 of a pH with the glass electrode and 0.13 of a pH with the quinhydrone electrode. Similar differences occurred with other soils. These results confirm those previously reported (5).

The analysis of variance shows also that the differences between means of time for each soil are highly significant. This implies that the pH values determined at various intervals of time change, and that these changes are large in some cases and statistically signifi-

TABLE I.—*The pH of the supernatant liquid of quadruplicate samples of soil at various periods of time after mixing the soil and water, the determinations being made with glass and quinhydrone electrodes.*

Sample No.	Time in hours															
	0		¼		½		1		3		6		12		24	
	Glass	Quin.	Glass	Quin.	Glass	Quin.	Glass	Quin.	Glass	Quin.	Glass	Quin.	Glass	Quin.	Glass	Quin.
Tama Silt Loam																
1	5.03	5.09	5.03	5.13	5.04	5.13	5.01	5.11	4.99	5.09	4.98	5.03	5.18	5.20	5.26	5.31
2	5.08	5.13	5.04	5.26	5.04	5.13	5.03	5.08	5.01	5.08	5.04	5.08	5.18	5.21	5.25	5.33
3	5.04	5.09	5.06	5.16	5.04	5.18	5.04	5.11	4.99	5.04	5.03	5.11	5.16	5.20	5.21	5.25
4	5.06	5.09	5.06	5.16	5.03	5.11	5.03	5.08	5.01	5.08	5.01	5.04	5.16	5.21	5.26	5.26
Mean	5.05	5.10	5.05	5.18	5.04	5.14	5.03	5.10	5.01	5.07	5.02	5.07	5.17	5.21	5.24	5.29
Shelby Loam																
1	5.70	5.97	5.84	6.08	5.84	6.04	5.82	5.97	5.87	5.96	5.89	5.94	6.06	6.18	6.14	6.26
2	5.74	6.03	5.82	6.09	5.86	6.04	5.84	5.97	5.79	5.99	5.92	5.99	5.89	6.11	6.13	6.28
3	5.74	6.06	5.81	6.08	5.86	5.99	5.84	5.96	5.87	5.99	5.94	5.97	5.84	5.97	6.13	6.23
4	5.75	6.01	5.86	6.06	5.84	6.01	5.86	5.99	5.87	6.01	5.91	6.01	5.87	6.09	6.11	6.19
Mean	5.73	6.02	5.83	6.08	5.85	6.02	5.84	5.96	5.86	5.99	5.92	5.98	5.92	6.09	6.13	6.24
Carrington Loam																
1	5.21	5.28	5.18	5.31	5.16	5.26	5.20	5.30	5.23	5.23	5.18	5.23	5.28	5.38	5.70	5.86
2	5.26	5.40	5.16	5.28	5.16	5.28	5.18	5.25	5.23	5.21	5.23	5.25	5.25	5.37	5.67	5.82
3	5.18	5.31	5.18	5.26	5.21	5.28	5.16	5.25	5.20	5.21	5.21	5.23	5.21	5.33	5.75	5.87
4	5.20	5.30	5.20	5.28	5.16	5.26	5.18	5.28	5.23	5.23	5.20	5.25	5.25	5.31	5.62	5.79
Mean	5.21	5.32	5.18	5.28	5.17	5.27	5.18	5.27	5.22	5.21	5.21	5.24	5.23	5.35	5.69	5.84
Grundy Silt Loam																
1	5.25	5.37	5.40	5.48	5.33	5.43	5.38	5.47	5.40	5.48	5.45	5.57	5.57	5.64	5.62	5.72
2	5.16	5.40	5.37	5.48	5.33	5.47	5.37	5.43	5.33	5.45	5.37	5.48	5.50	5.62	5.64	5.74
3	5.26	5.40	5.35	5.47	5.31	5.47	5.35	5.43	5.35	5.42	5.40	5.47	5.55	5.64	5.60	5.72
4	5.20	5.38	5.40	5.50	5.33	5.48	5.35	5.42	5.35	5.47	5.42	5.53	5.57	5.60	5.60	5.69
Mean	5.22	5.39	5.38	5.48	5.33	5.46	5.36	5.44	5.36	5.46	5.41	5.51	5.55	5.63	5.62	5.72
Marshall Silt Loam																
1	7.53	7.07	7.58	7.07	7.38	7.07	7.53	6.85	7.53	7.11	7.48	6.90	7.33	7.12	6.92	7.16
2	7.48	7.06	7.55	7.04	7.38	7.09	7.50	6.97	7.53	6.65	7.51	7.14	7.40	7.06	7.04	6.87
3	7.55	7.04	7.40	6.85	7.29	7.04	7.58	6.77	7.43	6.89	7.45	7.02	7.23	7.01	7.18	6.96
4	7.56	7.09	7.53	7.03	7.36	7.09	7.55	6.97	7.55	6.96	7.48	7.09	7.26	7.04	7.18	6.79
Mean	7.53	7.07	7.52	7.00	7.35	7.07	7.54	6.89	7.51	6.90	7.48	7.04	7.31	7.06	7.08	6.94

TABLE 2.—*Analysis of variance of pH values of soil-supernatant liquids of five soils at various periods of time after mixing soil and water.*

Source of variation	Degrees of freedom	Mean square				
		Tama silt loam	Shelby loam	Carrington loam	Grundy silt loam	Marshall silt loam
Total	63	—	—	—	—	—
Between means of samples	3	0.0013	0.001	0.001	0.002	0.011
Between means of time	7	0.0516**	0.073**	0.276**	0.108**	0.06**
Between means of electrodes	1	0.068**	0.434**	0.116**	0.187**	2.797**
Interactions:						
Time—samples	21	0.0006	0.003**	0.0015**	0.0009*	0.007
Time—electrodes	7	0.0014	0.010**	0.0046**	0.002**	0.066**
Samples—electrodes	3	0.0007	0.001	0.0000	0.0007	0.005
Remainder	21	0.0008	0.0005	0.0003	0.0004	0.009

*Significant.
**Highly significant.

cant. It may be noted from the original data of Table 1, however, that only slight changes in pH occurred within the first 6 hours the various soils were in contact with water. The mean pH values changed within the first 6 hours only 0.04 pH in the case of Tama silt loam to only 0.19 pH in the case of Shelby loam when the determination was made with the glass electrode. The extent of this change is more clearly shown in the sums of the pH values obtained from quadruplicate samples as shown in Table 3.

It may be noted that the sums of the pH values obtained at different times with both glass and quinhydrone electrodes for the eight samples of soil varied within the 6-hour period to only a slight extent. Variations within this range are considered to be relatively unimportant for most soil reaction studies. After the 6-hour period, however, the pH of the soil-water mixture changed considerably with all the soils. In the acid soils the pH increased with an increase in time, as shown in the case of Tama silt loam when the mean pH increased 0.22 of a pH within the 6- to 24-hour period when the glass electrode method was used. A similar change occurred with the other acid soils, although the increase in pH within the 6- to 24-hour period for Carrington loam was considerably larger, being 0.48 of a pH using the glass electrode method. The magnitude of this change in pH after the 6-hour period is clearly evident when the sums of the pH values, as determined by both glass and quinhydrone electrodes on the eight soil samples, are considered.

In the basic soil, Marshall silt loam, there was practically no change in pH during the first 6 hours; but from the sixth to the twenty-fourth hours, however, there was a rather large decrease in pH when determined with either electrode.

Inasmuch as the pH of all the soils studied changed only slightly during the first 6 hours of the investigation, it is concluded that the statistically significant change in pH of the soils occurred after the 6-

TABLE 3.—*The sum of the results of pH determinations on quadruplicate samples of five soils at various intervals after mixing soil and water, the determinations being made on the soil-water supernatant liquid with glass and quinhydrone electrodes.*

Kind of electrodes	Time in hours								
	0	¼	½	1	3	6	12	24	Total
				Tama Silt Loam					
Glass	20.21	20.19	20.15	20.11	20.00	20.06	20.68	20.98	162.38
Quinhydrone	20.40	20.71	20.55	20.38	20.29	20.26	20.82	21.15	164.56
Total	40.61	40.90	40.70	40.49	40.29	40.32	41.50	42.13	326.94
				Shelby Loam					
Glass	22.93	23.33	23.40	23.36	23.40	23.66	23.66	24.51	188.25
Quinhydrone	24.07	24.31	24.08	23.89	23.95	23.91	24.35	24.96	193.52
Total	47.00	47.64	47.48	47.25	47.35	47.57	48.01	49.47	381.77
				Carrington Loam					
Glass	20.85	20.72	20.69	20.72	20.89	20.82	20.99	22.74	168.42
Quinhydrone	21.29	21.13	21.08	21.08	20.88	20.96	21.39	23.34	171.15
Total	42.14	41.85	41.77	41.80	41.77	41.78	42.38	46.08	339.57
				Grundy Silt Loam					
Glass	20.87	21.52	21.30	21.45	21.43	21.64	22.19	22.46	172.86
Quinhydrone	21.55	21.93	21.85	21.75	21.82	22.05	22.50	22.87	176.32
Total	42.42	43.45	43.15	43.20	43.25	43.69	44.69	45.33	349.18
				Marshall Silt Loam					
Glass	30.12	30.06	29.41	30.16	30.04	29.92	29.22	28.32	237.25
Quinhydrone	28.26	27.99	28.29	27.56	27.61	28.15	28.23	27.78	223.87
Total	58.38	58.05	57.70	57.72	57.65	58.07	57.45	56.10	461.12

hour period. It is evident, therefore, that for practical purposes, where determinations are to be made within a few minutes after mixing the soil with water, the time factor has no significant influence on the results obtained.

The results of the statistical analysis in Table 2 show also that the difference between the means of electrodes is highly significant. As may be noted from the original data in Table 1, the glass electrode gave consistently lower pH values than the quinhydrone electrode in acid soils. The differences in the mean pH values obtained with the glass and quinhydrone electrodes varied, in the case of the Tama silt loam from 0.04 of a pH to 0.13 of a pH during the 24-hour period, the largest differences during the 24-hour period being from 0.06 to 0.29 pH. Other acid soils gave similar results. This difference between electrodes is more clearly shown when the sums of all the pH values of each soil, when determined with the glass electrode, are compared with the sums of all pH values of each soil when determined with the quinhydrone electrode. For instance, it may be noted from Table 3 that, with the Tama silt loam, the sum of the pH values obtained with the glass electrode was 162.38 in comparison with 164.56 obtained with the quinhydrone electrode. Similar differences in the sum of pH values were obtained with the other acid soils. With the basic Marshall silt loam, the glass electrode gave consistently higher pH values than the quinhydrone electrode. The sum of the pH values with this soil was 237.25 for the glass electrode and 223.87 for the quinhydrone electrode. These results confirm those previously published (5).

Because of the comparatively small range of variability of the results obtained with either the glass or the quinhydrone electrode, the differences in average results between the two electrodes have proved statistically significant. It is believed, however, that these differences are still within a range wherein differences are relatively unimportant for most soil reaction studies.

The analysis of the data also shows that the interaction between time and samples is significant in three soils. This means that the order of the reaction of different soil samples changed from time to time, or that the magnitude of the differences between samples at different times was larger than in the case of the soils which show a non-significant interaction. It may be observed further that the interaction between time and electrodes is highly significant with all but one soil, the Tama silt loam. This interaction shows that, although there was a significant difference between means of electrodes and that the values obtained were always higher for one electrode on a particular soil, as was pointed out above, the difference between electrodes was not of the same magnitude at different times. The analysis in Table 2 shows further that the interaction between samples and electrodes was not significant in any case, indicating that both electrodes behaved in the same manner on the same samples of soil.

REACTION STUDIES ON SOIL SUSPENSIONS

In this experiment the same general procedure was followed as in the previous one, except that the pH was determined with the electrodes immersed in soil suspensions instead of in the supernatant liquid of the soil-water mixture. At the various designated times the soil-water mixture was shaken vigorously for 15 seconds, the suspension poured into the U-shaped tube, and the hydrogen-ion concentration determined. The results of this study are presented in Table 4. Recognizing the variability within the data of this table, it seemed desirable to analyze the data statistically by the analysis of variance method. The results of this analysis are shown in Table 5.

The data show that the means between samples are not significant except for the Marshall silt loam. This means that the pH of the quadruplicate samples of the Tama, Shelby, Carrington, and Grundy soils did not vary sufficiently to be statistically different. In other words, the quadruplicate results are indicative of homogeneity. In the case of the Marshall silt loam, however, there was some difference in the pH values obtained with quadruplicate samples at various times. The largest range of variation in pH for the quadruplicate samples of this soil was 0.13 pH when the glass electrode was used and 0.12 pH when the quinhydrone electrode was employed. Although this variability was sufficiently large to in-

TABLE 4.—*The pH of the soil suspension of quadruplicate samples of soil at various periods of time after mixing soil and water, the determinations being made with glass and quinhydrone electrodes.*

Sample No.	Time in hours															
	0		¼		½		1		3		6		12		24	
	Glass	Quin.	Glass	Quin.	Glass	Quin.	Glass	Quin.	Glass	Quin.	Glass	Quin.	Glass	Quin.	Glass	Quin.
Tama Silt Loam																
1	4.91	5.03	4.98	5.04	4.94	5.01	4.93	5.06	5.01	5.06	4.93	5.08	4.93	5.09	5.06	5.20
2	4.89	5.01	5.03	5.03	4.96	5.01	4.94	5.04	4.91	4.99	4.96	5.13	4.96	5.13	5.09	5.25
3	4.91	5.01	4.93	5.03	4.93	5.01	4.91	4.99	4.96	5.01	4.98	5.06	4.94	5.11	5.09	5.26
4	4.86	4.99	4.96	5.06	4.91	5.01	4.94	4.99	4.86	5.01	4.99	5.04	4.98	5.11	5.15	5.28
Mean	4.89	5.01	4.97	5.04	4.94	5.01	4.93	5.02	4.93	5.02	4.97	5.08	4.95	5.11	5.10	5.25
Shelby Loam																
1	5.72	5.96	5.70	5.97	5.70	6.03	5.77	5.91	5.74	6.03	5.79	6.03	5.75	6.04	5.89	6.03
2	5.82	5.77	5.74	6.01	5.75	6.01	5.77	5.97	5.81	6.01	5.79	5.96	5.79	6.01	5.86	6.04
3	5.82	5.96	5.75	6.04	5.74	5.96	5.74	5.99	5.77	6.03	5.82	5.89	5.77	5.97	5.89	6.01
4	5.81	5.97	5.81	6.04	5.74	5.96	5.81	5.97	5.79	5.99	5.77	5.96	5.77	6.01	5.94	6.03
Mean	5.79	5.96	5.75	6.02	5.73	5.99	5.77	5.96	5.78	6.02	5.79	5.96	5.77	6.01	5.90	6.03
Carrington Loam																
1	5.21	5.30	5.20	5.30	5.20	5.33	5.21	5.30	5.20	5.26	5.21	5.33	5.30	5.33	5.50	5.55
2	5.18	5.26	5.20	5.31	5.21	5.33	5.20	5.30	5.23	5.28	5.26	5.35	5.28	5.33	5.45	5.59
3	5.23	5.28	5.21	5.30	5.18	5.31	5.16	5.30	5.21	5.37	5.28	5.31	5.28	5.30	5.45	5.57
4	5.20	5.30	5.21	5.30	5.23	5.31	5.20	5.28	5.23	5.33	5.23	5.30	5.28	5.31	5.47	5.55
Mean	5.21	5.29	5.21	5.30	5.21	5.32	5.19	5.30	5.22	5.31	5.25	5.32	5.29	5.32	5.47	5.57
Grundy Silt Loam																
1	5.26	5.31	5.25	5.37	5.30	5.37	5.30	5.35	5.38	5.40	5.26	5.38	5.40	5.43	5.42	5.38
2	5.21	5.33	5.16	5.35	5.31	5.35	5.28	5.33	5.26	5.40	5.28	5.37	5.43	5.40	5.40	5.40
3	5.21	5.33	5.25	5.35	5.28	5.35	5.25	5.33	5.23	5.40	5.28	5.33	5.40	5.40	5.43	5.45
4	5.26	5.31	5.21	5.38	5.30	5.37	5.25	5.35	5.23	5.38	5.23	5.35	5.43	5.38	5.40	5.40
Mean	5.24	5.32	5.22	5.36	5.30	5.36	5.27	5.34	5.28	5.40	5.26	5.36	5.42	5.40	5.41	5.41
Marshall Silt Loam																
1	7.55	7.53	7.50	7.56	7.51	7.55	7.55	7.58	7.51	7.56	7.46	7.50	7.45	7.55	7.41	7.41
2	7.50	7.53	7.53	7.60	7.55	7.60	7.53	7.63	7.50	7.58	7.50	7.53	7.50	7.62	7.41	7.45
3	7.50	7.56	7.58	7.58	7.56	7.56	7.55	7.65	7.50	7.62	7.46	7.51	7.48	7.58	7.41	7.43
4	7.50	7.56	7.63	7.63	7.56	7.62	7.51	7.65	7.48	7.50	7.50	7.55	7.46	7.65	7.43	7.45
Mean	7.51	7.55	7.56	7.59	7.55	7.58	7.54	7.63	7.50	7.57	7.48	7.52	7.47	7.60	7.42	7.44

TABLE 5.—*Analysis of variance of pH values of water suspensions of five soils at various periods of time after mixing soil and water.*

Source of variation	Degrees of freedom	Mean square				
		Tama silt loam	Shelby loam	Carrington loam	Grundy silt loam	Marshall silt loam
Total	63	——	——	——	——	——
Between means of samples	3	0.0003	0.001	0.000	0.001	0.003**
Between means of time	7	0.039**	0.009**	0.066**	0.204**	0.020**
Between means of electrodes	1	0.182**	0.635**	0.121**	0.078**	0.051**
Interaction:						
Time—samples	21	0.0014	0.0014	0.0005	0.0007	0.001
Time—electrodes	7	0.0023*	0.008**	0.0013*	0.006**	0.003**
Samples—electrodes	3	0.0003	0.007**	0.0003	0.001	0.0007
Remainder	21	0.0007	0.001	0.0005	0.0007	0000.6

*Significant.
**Highly significant.

dicate real differences between the different samples of soil, in this case it is believed that they are still within a range wherein the differences are relatively unimportant for most soil reaction studies. Assuming this to be true, the data of this experiment, obtained by determining the pH in soil suspensions, are in agreement with those obtained in the previous experiment where the determinations were made on the supernatant liquid.

It may also be observed that the differences in pH between means of time are highly significant with all soils, meaning that the pH values determined at various intervals of time changed and that the changes were large in some cases and statistically significant. The data in Table 4, however, show that only slight changes in pH occurred during the first 12 hours the soils were in contact with water when the determination was made by either electrode. As may be noted in the case of the Carrington loam, the mean pH of quadruplicate samples varied only 0.10 of a pH during the first 12 hours, and when the sums of the pH values, as shown in Table 6, are compared, it is more clearly shown that the changes in pH during the first 12 hours were small. These changes are considered of doubtful significance in soil reaction studies. Larger changes in pH values, however, occurred after the 12-hour period the soil was in contact with water. As shown with the Carrington loam, the mean pH of quadruplicate samples increased from 5.29 at the twelfth hour to 5.47 at the twenty-fourth hour when determined with the glass electrode. A similar change occurred when the quinhydrone electrode was used, the change being 0.25 pH. This change is emphasized by the sums of the quadruplicate pH values. Hence these data clearly indicate a definite increase in pH after the 12-hour period when either electrode is used. It may be concluded, therefore, that the significant change in pH values of the soil suspensions occurred after the twelfth hour, and that since there is no practical advantage in allowing soil to remain in contact with water more than 1 or 2 hours in routine determinations, the time factor is of no importance in determining the pH of soils with either of these electrodes.

TABLE 6.—*The sum of the results of pH determinations on quadruplicate samples of five soils at various intervals after mixing soil and water, the determinations being made on soil suspensions with glass and quinhydrone electrodes.*

Kind of electrodes	Time in hours								
	0	¼	½	1	3	6	12	24	Total
Tama Silt Loam									
Glass	19.57	19.88	19.74	19.72	19.74	19.86	19.81	20.39	158.71
Quinhydrone	20.04	20.16	20.04	20.08	20.07	20.31	20.44	20.99	162.13
Total	39.61	40.04	39.78	39.80	39.81	40.17	40.25	41.38	320.84
Shelby Loam									
Glass	23.17	23.00	22.93	23.09	23.11	23.17	23.08	23.58	185.13
Quinhydrone	23.66	24.06	23.96	23.84	24.06	23.84	24.03	24.11	191.56
Total	46.83	47.06	46.89	46.93	47.17	47.01	47.11	47.69	376.69
Carrington Loam									
Glass	20.82	20.82	20.82	20.77	20.87	20.98	21.14	21.87	168.09
Quinhydrone	21.14	21.21	21.28	21.18	21.24	21.29	21.27	22.26	170.87
Total	41.96	42.03	42.10	41.95	42.11	42.27	42.41	44.13	338.96
Grundy Silt Loam									
Glass	20.94	20.87	21.19	21.08	21.10	21.05	21.66	21.65	169.54
Quinhydrone	21.28	21.45	21.44	21.36	21.58	21.43	21.61	21.63	171.78
Total	42.22	42.32	42.63	42.44	42.68	42.48	43.27	43.28	341.32
Marshall Silt Loam									
Glass	30.05	30.24	30.18	30.14	29.99	29.92	29.89	29.66	240.07
Quinhydrone	30.18	30.37	30.33	30.51	30.26	30.09	30.40	29.74	241.88
Total	60.23	60.61	60.51	60.65	60.25	60.01	60.29	59.40	481.95

The statistical analysis also shows that the differences between means of electrodes are at least significant for every soil and highly significant in all but the Shelby loam. This indicates that the glass and quinhydrone electrodes did not give the same pH values for the soils studied. It is obvious from the original data that the glass electrode gave consistently lower pH values than the quinhydrone electrode for these soils. This point is clearly shown by the sums of the pH values shown in Table 6. These results agree with those of the previous test except that the glass electrode gave lower results with all the soils in this case, whereas the glass electrode gave higher results for the Marshall silt loam when the determinations were made on the supernatant liquid.

The statistical analysis also shows that the interaction between time and samples is not significant. This indicates that the differences in the pH values of different soil samples were not large at the various times. The interaction between time and electrodes is significant for all soils and highly significant for the Shelby, Grundy, and Marshall soils. This significant interaction shows that, although there was a significant difference between means of electrodes, and that the pH values obtained were always higher for one electrode on a particular soil, the difference between electrodes was not of the same magnitude at different times. The analysis shows further that the interaction between samples and electrodes was highly significant with only one soil, the Shelby loam. This indicates that the two electrodes did not behave in the same manner on the same samples of this soil. The electrodes did behave similarly, however, with samples of the other four soils.

In general, it may be observed from the data of these two experiments that similar results were obtained when determining the pH in soil suspensions or in supernatant liquids of the soils studied within the first 6 hours, and that somewhat different results were obtained with the two methods after that period.

During the progress of these experiments it was observed that the soil sample in which the pH is being determined may be shaken without appreciably changing the potential. It was observed with the glass electrode, however, that the potential may be changed considerably by merely moving the electrode up and down in the soil suspension. It is believed desirable, therefore, that the glass electrode be raised up and down in the solution only two or three times when the electrode is placed in the soil-water mixture. The electrode should then be left undisturbed until the pH has been determined.

SUMMARY AND CONCLUSIONS

Experiments were conducted to determine the influence on the hydrogen-ion concentration of five Iowa soils of the length of time soil is in contact with water in suspension. Seventy-five cc of distilled water were added to 35 grams of soil and allowed to stand for 0, ¼-, ½-, 1-, 3-, 6-, 12-, and 24-hour intervals, after which hydrogen-ion concentration was determined by the glass and quinhydrone electrodes on soil suspensions and on supernatant liquids. The data were analyzed statistically by the analysis of variance and the following conclusions have been drawn:

1. The variability in the pH of quadruplicate samples of different soils at any time was comparatively small when determinations were made in either the supernatant liquid or the soil suspension.

2. There was very little change in the pH of the supernatant liquids or the soil suspensions during the first 6 and 12 hours, respectively, after preparation. After that time, however, there was a significant increase in the pH of the acid soils and a decrease in the pH of the basic soil. This change in pH is presumably of no practical significance as it does not occur until a rather long time after preparation of the samples for pH determination.

3. The glass electrode method gave consistently lower results than the quinhydrone electrode method in all soils, except in the supernatant liquid of Marshall silt loam where it gave slightly higher results. The differences obtained by the two methods were so small that they are considered of little significance in actual practice.

4. Repeated moving up and down of the glass electrode in the soil-water mixture resulted in lower pH values of the soils studied. It is recommended, therefore, that the electrode be moved up and down only two or three times in the soil-water mixture immediately after immersion and that it then be left undisturbed until the pH determination is made.

LITERATURE CITED

1. BAVER, L. D. The drift in the potential of the quinhydrone electrode. Jour. Amer. Soc. Agron., 20: 1125–1140. 1928.
2. BIILMAN, E., and JENSEN, S. T. On the determination of the reaction of soils by means of the quinhydrone electrode. Trans. Sec. Comm. Int. Soc. Soil Sci., B : 236–274. 1927.
3. CLARK, NORMAN ASHWELL, and COLLINS, EMERSON R. The quinhydrone electrode and the soil reaction. Soil Science, 24 : 453–463. 1927.
4. DEAN, HAROLD L., and WALKER, R. H. A comparison of glass and quinhydrone electrodes for determining the pH of some Iowa soils: I. A comparison of different types of glass electrodes. Jour. Amer. Soc. Agron., 27 : 429-436. 1935.
5. ———, ———. A comparison of glass and quinhydrone electrodes for determining the pH of some Iowa soils: II. The variability of results. Jour. Amer. Soc. Agron., 27 : 519-525. 1935.
6. HISSINK, D. J., and VAN DER SPEK, JAC. Die pH Bestimmung des Bodens nach der Biilmann'schen Chinhydronmethode. Trans. Sec. Comm. Int. Soc. Soil Sci., A : 29–40. 1926.
7. NAFTEL, J. A. The glass electrode and its application in soil acidity determinations. Soil Res., 4 : 41–50. 1934.
8. SNEDECOR, GEORGE W. Calculation and Interpretation of Analysis of Variance and Covariance. Ames, Iowa : Collegiate Press, Inc. 1934.

THE MECHANISM OF PHOSPHATE RETENTION BY NATURAL ALUMINO-SILICATE COLLOIDS[1]

GEORGE D. SCARSETH[2]

THE problem of supplying plants with phosphorus is of extreme importance and is complicated by the fact that the colloidal fraction of soils has the inherent property of converting soluble phosphates of fertilizers into insoluble forms. Various investigators have done much to clarify the behavior of phosphates in the soil, but there is still a lack of agreement in the interpretation of the results obtained. This lack of agreement appears to arise from the failure to take into account some of the important factors that affect the behavior of phosphates in soils. The principal functional fraction of a soil is made up of interrelated colloidal systems called colloidal ampholytes by Mattson and Pugh (8).[3] Since the surfaces of these systems attract cations and anions with electrostatic forces which vary in magnitude according to the environmental conditions of temperature, concentration, and reaction, it becomes obvious that the interpretation of any specific experimental data requires the careful consideration of many factors.

The vast literature which relates to phosphate behavior cannot be reviewed here. It is sufficient to refer only to those investigations which served as stepping stones to the plan of this study.

Roszman (13), in 1927, suggested the possibility that the clay complex might be partially responsible for the retention of phosphates. The author's investigations (14, 15, 16) indicated that the retention of phosphates by soils was more complicated than could be explained with data from heterogeneous soil colloidal systems. It was necessary to have information from simpler systems in order better to understand the chemistry of the phosphates and the physico-chemical constitution of the soil colloids before the concept of the present study could be developed. The work of Gaarder (7) and of Mattson (9) were especially valuable in this connection.

Gaarder has clearly set forth the behavior of the phosphate ion in the presence of free ions of iron, aluminum, calcium, magnesium, and sodium. Mattson contends that soil colloids are principally amphoteric precipitates which have surface valences that vary in their attractive forces for different cations and anions, and that the electrostatic forces and the sign of the valences depend upon the pH

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[3] Reference by numbers in parenthesis is to "Literature Cited," p. 615.

of the medium. In 1931, Bradfield (2) suggested the probability that phosphates are in part retained on the surfaces of the alumino-silicates in the soils and may be replaced by other anions. Recently, Demolon (6), Ravikovitch (12), and Pugh (11) have published papers dealing with the ionic exchange of phosphates.

The present investigation was started in 1932 when the concept of anion exchange had received almost no experimental verification. This paper reports only the most significant data obtained in an investigation of the mechanism of phosphate retention by relatively simple, alumino-silicate colloidal systems of varying compositions at different pH values in the presence of calcium or sodium cations. An attempt is made to interpret the results in order to give a clearer understanding of the mechanism of phosphate retention by soils. Special attention is given to the verification of the data with growing plants on normal soils.

PHOSPHATE RETENTION BY ALUMINO-SILICATE COLLOIDS OF LOW AND HIGH IRON CONTENT

PREPARATION OF MATERIAL

The alumino-silicate colloid used was prepared from a low-iron (3.1% Fe_2O_3) bentonite by agitating the bentonite in water in a barrel churn for 8 hours and allowing the suspension to settle for about 15 hours. The material remaining in suspension was then syphoned off and run into a Sharples supercentrifuge. The suspension passing through the centrifuge at 18,000 r. p. m. was concentrated by removing water in the process of electrodialysis. The silica-sesquioxide ratio of the electrodialized colloid was 4.54. Over 68% of the colloidal particles were less than 125 millimicrons in diameter. The pH and conductivity curves for the colloid when titrated with 0.042 N $Ca(OH)_2$ are given in Fig. 1. These show that the critical deflection points in both pH and conductivity occur at about 100 M. E. of the cation per 100 grams of the colloid.

The general scheme of experimental procedure is given diagrammatically in Fig. 2. The colloid designated as "high in iron" was enriched with iron by the addition of $FeCl_2$ to the electrodialized bentonite colloid. This "ferriferated" alumino-silicate was then electrodialized to remove the mobile ions of Cl and Fe. During the initial period (5 days) of this dialysis, the pH of the colloid was maintained near 4.5 by frequent additions of NaOH. At this reaction the unsorbed iron was carried away from the colloid to the cathode membrane of the cell where it could be removed. The added Na ions acted as conductors of the electric current and thus facilitated the removal of the Cl ions. In order to make the newly formed colloid uniform throughout in respect to oxidation and reduction, a 3% solution of H_2O_2 was added. The colloid was then electrodialized without the addition of more NaOH until it was free of all mobile ions. This colloid then contained 6.3% Fe_2O_3. Since the iron retained was sorbed on the surfaces of the alumino-silicate colloid, it is valid to assume that the "ferriferated" alumino-silicate colloid would exhibit characteristics of a soil colloid rich in iron.

The individual colloidal systems on which all determinations were made consisted of 2 grams of the colloid in a final volume of 250 cc. The phosphorus was added in the form of H_3PO_4 to each series in four concentrations consisting of 3.2, 6.5, 12.9, and 25.8 millimols of H_3PO_4 per 100 grams of the colloid. The hydroxides of calcium and sodium were added in such progressively increasing amounts to the four series indicated in Fig. 1 that the final pH values would be over a wide range.

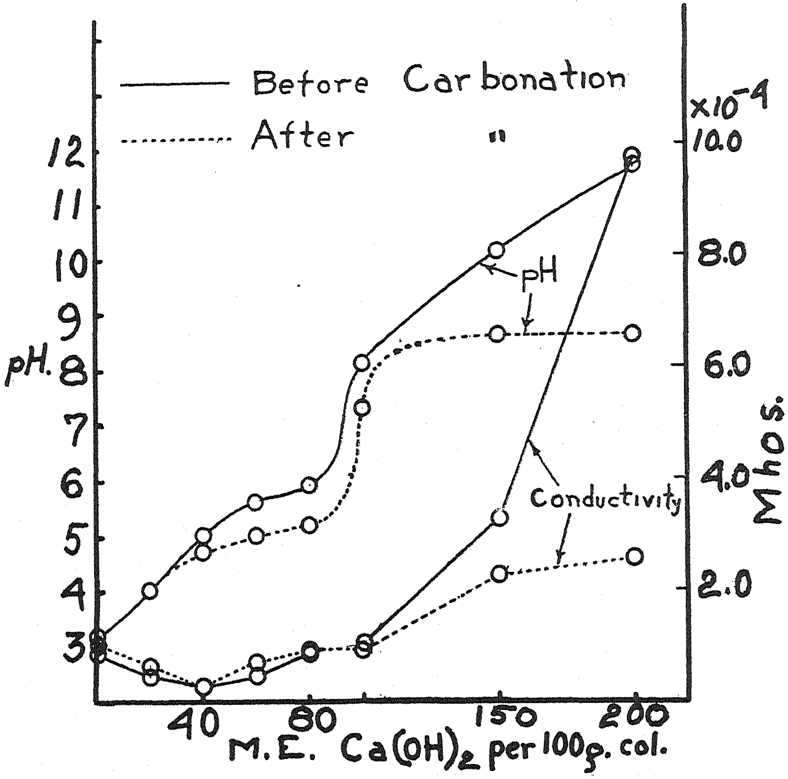

FIG. 1.—The relation of the pH and conductivity of the electrodialized alumino-silicate (bentonite) colloid to the concentration of $Ca(OH)_2$ before carbonation and after carbonation when equilibrated to the CO_2 content of ordinary air.

DETERMINATIONS AND METHODS

The data obtained from these systems consisted of determinations for the pH value, the electrical conductivity, and the phosphorus remaining in solution. (The difference between the amounts of phosphorus added and that remaining in solution was taken to represent the amount of phosphorus retained by the colloid.) These determinations were made on each individual system before treatment with CO_2 and also after aspirating with CO_2 and equilibrating them with air according to the method of Bradfield and Allison (4). In order to determine when equilibrium was approached in the systems, all of these determinations were made at the end of 1, 5, and 15 days after the set-up in the case of the low-iron colloids. It was found that equilibrium was established at the end of 24 hours in the acid ranges, but at the most alkaline reactions, pH 9.0 to 11.0, there was still some shift even at the end of 15 days.

The pH determinations were made by the glass electrode method (10) and the phosphorus was determined by an adaptation of the colorimetric method of Benedict and Theis (1). The clear extract for the phosphorus determination was obtained by centrifuging the colloid suspension. The systems containing Na were centrifuged until the bulk of the colloid settled out of suspension; then an aliquot sample of the suspension, which was nearly free of suspended colloid, was transferred to a second centrifuge tube where sufficient NaCl was added to cause the remaining suspended colloid to flocculate. When this was centrifuged a clear extract was obtained. A check was made to estimate the error introduced by this procedure of flocculation by comparing it with a similar system where the NaCl was not added and where the clear extract was obtained by dialysis. No measurable error was noted.

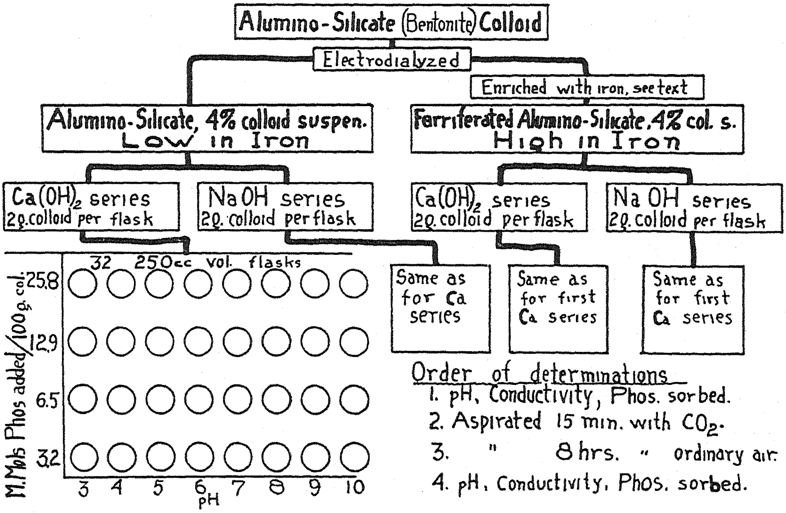
Alumino-Silicate (Bentonite) Colloid
Electrodialyzed
Enriched with iron, see text
Alumino-Silicate, 4% colloid suspen. Low in Iron
Ferriferated Alumino-Silicate, 4% col. s. High in Iron
Ca(OH)2 series 2g. colloid per flask
NaOH series 2g. colloid per flask
Ca(OH)2 series 2g. colloid per flask
Na OH series 2g. colloid per flask
32 250cc vol. flasks
M.Mols Phos added/100g. col.
25.8
12.9
6.5
3.2
3 4 5 6 7 8 9 10
pH
Same as for Ca series
Same as for first Ca series
Same as for first Ca series
Order of determinations
1. pH, Conductivity, Phos. sorbed.
2. Aspirated 15 min. with CO2.
3. " 8 hrs. " ordinary air.
4. pH, Conductivity, Phos. sorbed.

FIG. 2.—General scheme of experimental procedure.

RESULTS OBTAINED

Table 1 contains the data on the amount of phosphate retained by the low-iron content colloid. Since a field soil contains abundant CO_2 that will convert any excess hydroxides into carbonates, the most practical phases of the data in Table 1 are those obtained after the systems were carbonated and equilibrated to the CO_2 content of ordinary air. These data have been graphed in Fig. 3. It will be noted that the two families of curves in Fig. 3 have certain characteristics that are functions of the kind of cation present; for example, all the phosphate is retained at the high pH values in the Ca-series, while little or no phosphate is retained at the high pH values in the Na-series. (No significance can be attached to the data obtained at pH values above 8.0 in the presence of Na ions because it was found that in these instances the colorimetric method for determining soluble phosphorus gave abnormally high values. It appears that some

TABLE 1.—*Phosphate retained from solutions varying in concentrations of H_3PO_4 by electrodialized, low-iron content, alumino-silicate colloidal systems that differ in pH values by the addition of $Ca(OH)_2$ or NaOH; data obtained before and after equilibration with CO_2 and reported on the basis of 100 grams of the colloid.*

M. Mols H_3PO_4 added	Calcium series							Sodium series						
	M.E. Ca added	Before carbonation			After carbonation			M.E. Na added	Before carbonation			After carbonation		
		pH	Cond. 30° C $X10^{-5}$	PO_4 retained M. Mols	pH	Cond. 30° C $X10^{-5}$	PO_4 retained M. Mols		pH	Cond. 30° C $X10^{-5}$	PO_4 retained M. Mols	pH	Cond. 30° C $X10^{-5}$	PO_4 retained M. Mols
3.2	0.0	3.2	22.5	Nil	3.3	11.4	Nil	0.0	3.3	17.7	0.2	3.3	14.9	0.5
	25.2	3.8	7.2	1.2	3.8	5.2	1.2	13.3	4.3	5.5	0.4	4.0	6.1	1.1
	50.4	4.9	2.0	3.1	5.2	1.6	3.1	26.6	5.2	4.1	1.6	5.0	4.3	1.6
	69.4	5.6	2.0	3.2	5.6	1.5	3.2	47.9	6.3	4.4	3.2	6.1	4.1	3.2
	84.0	6.0	2.2	3.1	6.4	2.8	3.1	69.1	6.6	4.5	3.2	6.4	4.8	3.1
	92.5	6.8	3.8	2.8	7.0	3.6	2.5	90.5	7.2	8.3	1.3	7.1	9.9	1.7
	111.5	7.9	8.3	1.7	8.0	11.7	2.2	111.7	9.4	18.1	—0.5	8.0	23.5	0.5
	157.5	10.6	19.1	3.2	8.9	33.0	3.1	159.5	11.1	67.7	—0.9	8.9	55.4	Nil
6.5	0.0	3.2	18.9	Nil	3.2	19.8	Nil	0.0	3.2	19.7	0.4	3.7	21.8	0.9
	29.4	3.8	9.9	2.2	3.8	8.5	2.4	15.9	4.2	8.3	0.9	4.4	9.4	2.3
	54.4	5.0	2.7	5.1	5.1	2.7	5.4	31.9	5.2	7.0	2.0	5.4	6.9	3.1
	73.6	5.7	2.1	6.3	5.6	1.7	6.2	53.2	6.1	6.1	4.5	6.3	6.4	5.0
	88.2	6.4	2.7	6.3	6.2	3.4	5.8	74.5	6.6	6.9	5.1	6.6	8.1	5.0
	96.6	7.0	3.9	6.0	7.3	4.1	5.2	95.9	7.6	11.8	1.4	7.5	29.7	Lost
	117.8	8.2	8.5	4.6	8.1	12.4	5.3	117.0	9.5	22.2	—0.9	8.2	31.8	—0.6
	168.0	10.7	17.6	6.5	8.7	33.4	6.5	170.0	11.3	70.4	—1.3	8.9	88.7	—1.0
12.9	0.0	3.0	31.6	1.0	2.9	31.2	2.5	0.0	3.1	32.8	1.0	3.5	34.8	1.4
	44.2	3.9	11.8	6.0	3.7	10.0	5.8	21.2	3.8	14.5	2.2	4.0	14.5	2.9
	69.4	4.8	5.0	10.4	4.7	4.1	10.2	39.9	4.9	11.0	3.7	5.0	13.1	3.9
	86.2	5.6	3.8	11.9	5.4	3.5	10.2	58.8	5.8	10.0	6.0	5.6	12.7	5.3
	98.7	6.3	6.0	10.5	6.5	4.8	8.5	74.5	6.3	8.9	6.7	6.6	13.3	9.6
	111.2	7.0	7.9	9.5	7.4	9.1	9.3	95.9	6.9	11.1	6.5	7.3	14.4	7.7
	134.2	8.0	10.2	9.9	8.1	Lost	10.2	127.6	8.5	30.8	—2.0	8.2	41.7	—0.2
	195.2	10.8	19.4	12.9	8.7	29.1	12.9	191.3	11.2	103.0	—2.8	8.7	74.2	Nil
25.8	0.0	2.9	61.0	3.7	2.8	60.5	3.1	0.0	2.9	66.0	1.0	3.0	64.2	1.2
	65.1	3.8	20.2	9.4	3.8	17.0	12.5	37.2	3.7	25.0	0.3	4.1	25.2	1.0
	94.5	4.9	11.8	16.3	4.8	10.5	16.6	69.1	5.2	18.6	7.7	5.5	21.8	5.1
	109.2	6.0	11.5	16.2	6.1	13.6	15.8	95.9	6.2	17.6	9.4	6.5	18.1	10.0
	126.0	6.8	13.0	19.0	7.0	14.6	18.2	111.7	6.9	23.9	9.7	7.1	31.9	7.7
	140.9	7.4	12.9	19.3	7.7	15.8	20.2	127.6	7.5	36.0	2.6	7.7	42.5	3.5
	164.0	8.0	13.6	21.9	8.0	13.1	23.4	165.0	9.6	62.2	—3.8	8.0	74.2	2.5
	230.0	10.4	12.5	25.8	8.3	23.7	25.8	234.0	11.3	127.7	—0.3	8.7	127.7	2.5

types of soluble silicates form a blue color with the test reagents similar to that formed with the phosphate.)

A close study of Fig. 3 shows that the alumino-silicate colloid is responsible for the phosphate retention at the slightly acid pH values. Except where only 3.2 millimols of H_3PO_4 were added, more phosphate was retained by the alumino-silicate colloid at the maximum point in the acid range where Ca instead of Na was the cation present. It will later be shown that this is a significant fact. The curves also show that insoluble calcium phosphate was formed in the Ca-series at the pH values above those at which the base exchange complex was saturated. It is obvious that insoluble calcium phosphate was formed from the free Ca ions not sorbed by the colloid in the presence of free $CaCO_3$. Proof of this is found in the Na-series where the phosphate in solution increased as the pH values increased. Sodium phosphates are soluble and calcium phosphates are insoluble at high pH values (7). Since there was not any free iron in these colloid systems the phosphate was not retained at the very acid pH values.

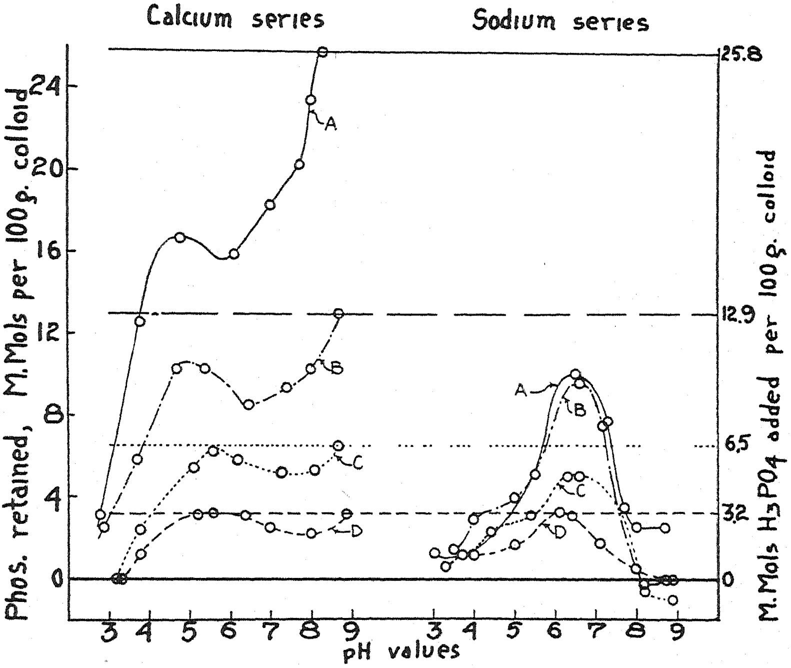

FIG. 3.—Graphic presentation of a portion of the data from Table 1, showing the relation between the phosphate retained by the *low-iron content* alumino-silicate colloids and the pH values in the presence of varying amounts of calcium or sodium and after the systems were equilibrated to the CO_2 content or ordinary air.

A, Phosphorus retained when 25.8 millimols of H_3PO_4 were added.
B, Phosphorus retained when 12.9 millimols of H_3PO_4 were added.
C, Phosphorus retained when 6.5 millimols of H_3PO_4 were added.
D, Phosphorus retained when 3.2 millimols of H_3PO_4 were added.

It is important to note that the amount of soluble phosphate was reduced by changing the reaction from very acid to only slightly acid. When the amount of soluble phosphate added was small (3.2 millimols of H_3PO_4), the retention was 100%. When the amount of soluble phosphate added was great, the retention was not complete.

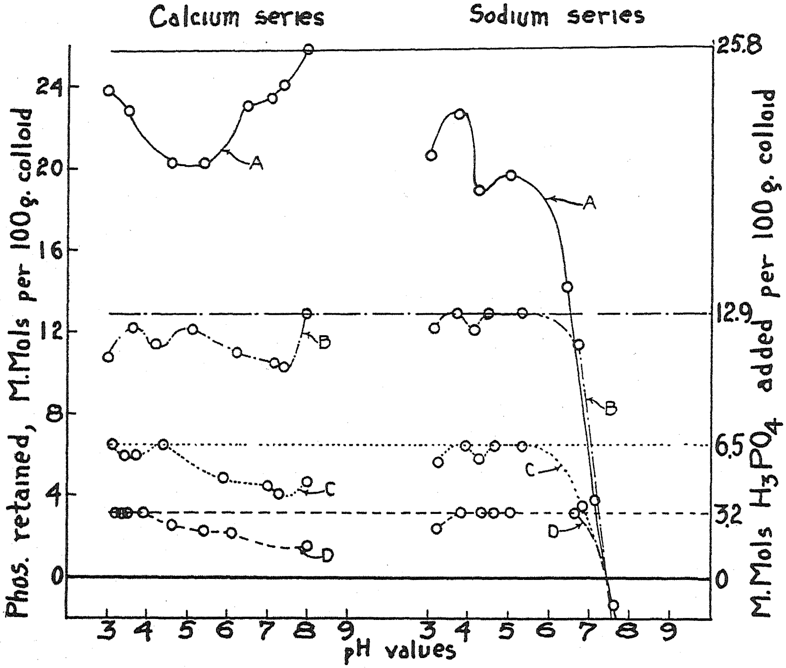

FIG. 4.—Graphic presentation of a portion of the data from Table 2, showing the relation between the phosphate retained by the *high-iron content*, ferriferated alumino-silicate colloids and the pH values in the presence of varying amounts of calcium or sodium and after the systems were equilibrated to the CO_2 content of ordinary air.

A, Phosphorus retained when 25.8 millimols of H_3PO_4 were added.
B, Phosphorus retained when 12.9 millimols of H_3PO_4 were added.
C, Phosphorus retained when 6.5 millimols of H_3PO_4 were added.
D, Phosphorus retained when 3.2 millimols of H_3PO_4 were added.

This behavior strongly indicates that the depressing effect which frequently results from light applications of lime to acid soils with colloids of high silica-sesquioxide ratio is caused by a decrease in the solubility of the phosphorus in the soil. If the soluble phosphate level is high, such as from a recent liberal application of a phosphate fertilizer, the depressing effect should not occur. The data definitely show that over-limed soils, i. e., soils with free $CaCO_3$ present after all the acids have been neutralized, would have little or no soluble phosphorus present.

Table 2 contains the data on the amount of phosphate retained by the high-iron content colloid. As in the case of the low-iron content colloid, the data obtained from the carbonated systems are most useful. These are graphed in Fig. 4. The most significant fact demonstrated here is that the phosphate was retained at the very acid pH values by the iron. Since Gaarder (7) has shown that iron does not affect the retention of phosphates at the more alkaline reactions and since the behavior of these colloidal systems at the high pH values are similar to those discussed for Fig. 3, they will not be discussed here. In the Ca-series it will be noted that where the added phosphate concentration was greatest (25.8 millimols H_3PO_4 per 100 grams colloid), the carbonation reduced the amount of phosphate retained at the pH values of 4.0 to 5.0. This might be accounted for by the formation of iron carbonates, thus reducing the amount of free iron in solution that would otherwise precipitate the phosphate. This evidence would support an hypothesis that actively decaying organic matter in very acid soils by producing CO_2 would benefit the fertility of the soil with respect to phosphorus by reducing the amount of active iron in the soil. When the rates of added phosphate were low in the Ca-series, the tendency was for the phosphate in solution to increase with the increase in pH values. But the behavior at the highest pH value in the presence of free calcium carbonate in the two cases where the retention was not complete is not entirely clear. It will be noted, however, (Table 2) that the retention was complete before the systems were carbonated.

These data indicate that no depressing effect from light applications of lime should occur in soils that have a low silica-sesquioxide ratio. In fact, any decrease in acidity from the very acid pH values should be beneficial. The injury from over-liming should be the same as described before regardless of the nature of the colloidal fraction.

ANION EXCHANGE

REPLACEMENT OF PO_4 BY THE HYDROXYL ANION

The data in Table 1 and in Fig. 3 show that the maximum phosphate retention by the low-iron alumino-silicate colloid occurred at the slightly acid pH values. In the Na-series the maximum retention occurred at about pH 6.1. As the pH values increased above this value, i. e., as the OH anion concentration increased, the electrostatic sorbing forces on the colloid became satisfied with OH anions instead of phosphate anions. The attractive force for the phosphate anions was inversely proportional to the concentration of the hydroxyl anions, thus the increase of phosphate ions in solution with the increase in pH values can be looked upon as an anion exchange phenomenon.

REPLACEMENT OF PO_4 BY THE SILICATE ANION

Since it was found that the phosphate anions were held by the alumino-silicate colloids at a slightly acid reaction, it would be enlightening to learn if this phosphate could be replaced by another somewhat similar anion. It would be necessary to make such a test without changing the reaction, as it has been shown that the hydroxyl anion would replace the sorbed phosphate anion. Such a test was made using the silicate anion from sodium silicate. The scheme of this experiment is given in Table 3, which also shows the data obtained at the end of 8 days. To show the relation between phosphate

TABLE 2.—*Phosphate retained from solutions varying in concentrations of H_3PO_4 by electrodialized, high-iron content, ferriferated aluminosilicate colloidal systems that differ in pH values by the addition of $Ca(OH)_2$ and NaOH; data obtained before and after equilibration with CO_2 and reported on the basis of 100 grams of the colloid.*

M. Mols H_3PO_4 added	Calcium series							Sodium series						
	M.E. Ca added	Before carbonation			After carbonation			M. E. Na added	Before carbonation			After carbonation		
		pH	Cond. 30° C X10^{-5}	PO_4 retained M. Mols	pH	Cond. 30° C X10^{-5}	PO_4 retained M. Mols		pH	Cond. 30° C X10^{-5}	PO_4 retained M. Mols	pH	Cond. 30° C X10^{-5}	PO_4 retained M. Mols
3.2	0.0	3.4	15.0	3.2	3.2	16.7	3.2	0.0	3.3	13.7	2.8	3.2	20.5	2.5
	25.2	3.7	12.5	3.2	3.3	13.2	3.2	12.5	4.0	10.9	3.2	3.8	14.3	3.2
	50.5	3.9	10.9	3.2	3.5	11.1	3.2	25.0	4.4	9.8	3.2	4.3	10.9	3.2
	69.4	4.4	10.2	3.2	3.9	10.8	3.2	45.0	4.7	9.6	3.2	4.6	11.1	3.2
	84.1	5.4	8.4	2.7	4.6	9.5	2.6	70.0	5.3	10.6	3.2	5.0	12.6	3.2
	92.5	6.4	10.0	2.7	5.4	9.8	2.3	90.0	6.4	15.4	2.8	6.6	15.5	3.2
	111.2	7.8	17.8	3.2	6.1	16.4	2.2	105.0	8.5	22.6	0.6	7.6	28.9	—1.2
	157.6	10.3	21.2	3.2	8.0	36.7	1.6	155.0	10.7	76.0	—1.3	8.5	74.6	—9.0
6.5	0.0	3.3	16.3	6.5	3.1	21.8	6.5	0.0	3.3	14.0	6.0	3.2	16.1	5.7
	29.4	3.6	13.8	6.5	3.4	14.4	6.0	15.0	3.9	9.9	6.5	3.9	11.5	6.5
	54.0	3.9	11.0	6.5	3.7	11.2	6.0	30.0	4.3	9.1	6.5	4.2	14.2	5.8
	73.5	4.6	11.2	6.5	4.4	9.1	6.5	50.0	4.8	10.0	6.5	4.6	11.5	6.5
	88.4	5.6	9.6	5.8	5.9	9.8	4.9	80.0	5.8	11.7	6.5	5.3	13.7	6.5
	96.6	6.3	10.6	6.0	7.0	9.0	4.5	95.0	L	17.8	5.3	6.8	20.8	3.6
	126.0	8.7	12.6	6.5	7.3	19.1	4.1	110.0	9.0	31.8	—5.0	7.8	40.2	—2.9
	178.5	10.4	23.4	6.5	8.0	41.0	4.7	160.0	10.6	74.6	—6.5	8.5	75.0	—18.5
12.9	0.0	3.3	18.8	11.7	3.0	19.6	10.8	0.0	3.2	16.9	11.7	3.1	19.2	12.1
	44.2	3.7	12.3	12.9	3.6	12.2	12.2	20.0	3.8	11.1	11.9	3.7	15.8	12.9
	69.2	4.5	9.2	12.9	4.2	9.9	11.4	37.5	4.2	11.1	12.4	4.1	14.2	12.1
	86.2	5.2	8.9	12.9	5.1	9.9	12.1	55.0	4.8	10.8	12.4	4.5	11.9	12.9
	98.8	6.1	11.1	12.2	6.3	10.5	11.0	80.0	5.6	13.6	11.9	5.3	13.2	12.9
	111.2	7.1	13.2	12.4	7.2	12.1	10.5	95.0	6.5	19.2	10.1	6.7	22.0	11.4
	136.5	8.4	13.7	12.6	7.4	22.8	10.2	125.0	8.6	40.6	3.2	7.9	45.4	—7.7
	197.5	10.3	24.6	12.9	8.0	38.7	12.9	180.0	10.7	97.8	1.8	8.6	97.7	—22.4

25.8	0.0	3.1	30.8	20.9	3.0	34.9	23.8	0.0	3.1	29.1	19.4	3.0	33.1	20.6
	65.1	3.6	16.7	24.9	3.5	19.3	22.8	35.0	3.7	18.0	21.0	3.7	19.1	22.6
	94.6	4.9	12.4	23.3	4.6	15.3	20.2	65.0	4.6	16.3	19.3	4.2	21.6	18.9
	105.0	5.7	14.6	23.9	5.4	16.1	20.2	90.0	5.4	16.5	19.3	5.0	19.1	19.6
	126.0	6.5	14.8	23.9	6.5	15.8	23.0	111.0	6.6	27.7	15.8	6.4	33.1	14.2
	140.8	7.3	17.5	23.7	7.1	20.5	23.4	125.0	7.0	43.8	15.3	7.1	54.6	3.9
	172.1	8.0	18.0	24.5	7.4	23.1	24.0	155.0	8.7	65.2	0.9	8.0	83.8	—3.5
	232.0	10.4	24.2	25.8	8.0	41.5	25.8	215.0	10.8	130.0	1.6	8.6	119.4	—0.8

TABLE 3.—*The replacement of phosphate sorbed by the low-iron content alumino-silicate colloid by sodium silicate.*

Electro-dialized colloid, grams per 250 cc	Millimols H_3PO_4 added per 100 grams colloid	Approximate millimols SiO_4 added per 100 grams colloid	Cc of N/10 NaOH added per 250 cc to maintain	Tests 8 days after set-up		
				pH	Millimols PO_4 in solution per 100 grams colloid	Millimols PO_4 replaced by silicate per 100 grams colloid
2	6.5	0.0	16.0	6.1	0.71	Nil
2	6.5	4.8	14.1	6.1	0.92	0.21
2	6.5	9.6	12.2	6.1	0.95	0.24
2	6.5	19.3	8.9	6.1	1.01	0.30
2	6.5	38.0	1.5	6.0	1.05	0.34
2	0	38.0	0.0	6.2	Nil	—

anions replaced and the concentration of the silicate anions, the results are plotted in Fig. 5. The magnitude of the amount of the phosphate anions replaced was not great, but it will be noted that replacement actually occurred and the curve obtained is a characteristic double log curve.

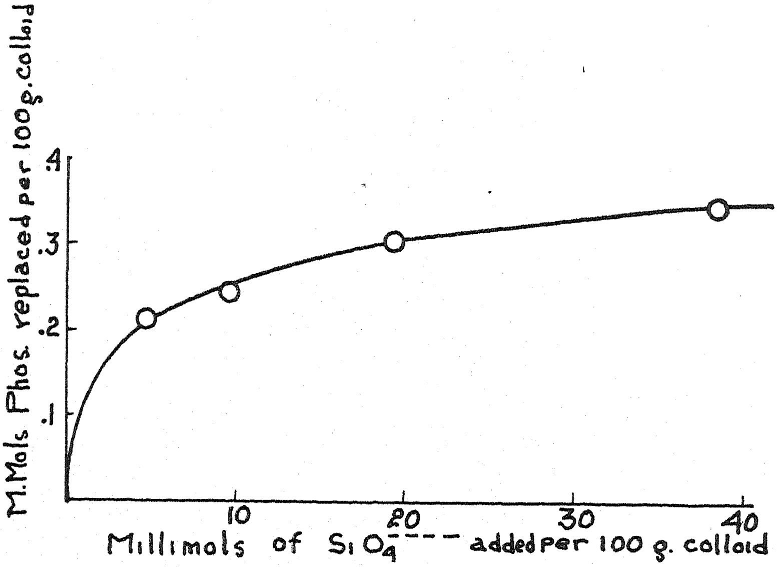

FIG. 5.—The replacement of the sorbed, insoluble phosphate on the low-iron content alumino-silicate colloid at pH 6.1 (pH changed with NaOH) by sodium silicate.

SUPPLEMENTARY DATA WITH PLANT TESTS

Four soils varying widely in several fundamental characteristics were studied in a greenhouse pot experiment to test out, by the use of growing plants, some of the findings in the laboratory investigations with the colloids. The principal object of these tests was to determine if the silicate anion would replace the native unavailable phosphate in various kinds of soils. The literature contains many references which show that silicates benefit plant growth and bear some relationship to the behavior of phosphates. Schollenberger (17) gives a good review of this point. However, this phenomenon has not been clearly demonstrated as an anion exchange reaction and it has not been shown how it is affected by the composition of the soil.

The soils used were Eutaw, Cecil, and Sumter clays, and Norfolk fine sandy loam. At the bottom of Table 4 are given some of the data on the more fundamental characteristics of these soils. Table 4 also shows the soil treatments, the yields of the sorghum crop after growing 97 days, and the available phosphorus (Truog's method) in the soil at the end of the test, 157 days after the soils were treated. The soils were treated 60 days before planting. This was done in order that the added materials and the soil would have time to reach equilibrium.

It will be noted that the "Promoloid,"[4] a colloidal magnesium silicate, and sodium silicate increased the growth of sorghum on only the Eutaw clay. This increased growth from the silicates is attributed to an increase in the availability of the native phosphate in the soil. The low yields on the no-phosphate treated pots and the amount of available phosphorus found in the soil of the silicate-treated pots are proofs of this. A photograph (Fig. 6), of some of the plants growing on the Eutaw clay shows further evidence of the replacement of the native phosphate in the soil.

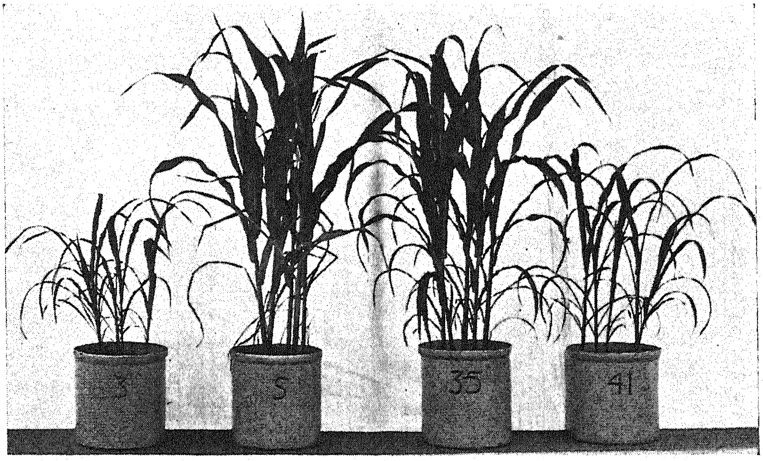

FIG. 6.—Sorghum growing on the Eutaw clay, showing evidence of the replacement of insoluble native soil phosphates by a silicate. Pot No. 3, no phosphate; pot No. 5, sodium phosphate, equivalent to 1 ton superphosphate per acre; pot No. 35, 2 tons sodium silicate per acre; pot No. 41, sodium bicarbonate, rate equivalent to the sodium in pot No. 35.

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[4] Sample of Asahi Promoloid obtained from the Kawahara Company, Los Angeles, Calif.

TABLE 4.—*The replacement by silicates of natural phosphates in soils varying widely in certain important characteristics in a greenhouse experiment with sorghum as the test crop.*

Pot No.	Treatment*	Rate per acre to the Eutaw clay†	Eutaw clay		Cecil clay		Norfolk fine sandy loam, virgin soil		Sumter clay	
			Yields of sorghum, grams	Avail. P, lbs. per acre	Yields of sorghum, grams	Avail. P, lbs. per acre	Yields of sorghum, grams	Avail. P, lbs. per acre	Yields of sorghum, grams	Avail. P, lbs. per acre
3	No phos.	———	7.5	Nil	1.1	Nil	2.0	Nil	1.3	Nil
5	Na-phos.	Equiv. to 1 ton superphosphate per acre	64.0	24.3	21.6	19.2	18.1	3.2	32.6	6.4
11	"Promoloid" Mg-silicate	4,000 lbs.	15.5	Nil	1.1	Nil	1.7	Nil	1.5	Nil
13	"Promoloid" Mg-silicate	16,000 lbs.	53.4	5.1	0.6	Nil	1.5	Nil	1.5	Nil
19	$MgSO_4$	Mg equiv. to Mg in pot 11	14.1	Nil	1.7	Nil	1.7	Nil	1.7	Nil
21	$MgSO_4$	Mg equiv. to Mg in pot 13	15.8	Nil	2.0	Nil	1.2	Nil	1.3	Nil
33	Na-silicate	1,000 lbs.	12.8	3.2	1.4	Nil	1.2	Nil	2.2	Nil
35	Na-silicate	4,000 lbs.	42.7	5.7	0.5	Nil	0.6	Nil	8.3	Nil
39	$NaHCO_3$	Na equiv. to Na in pot 33	7.8	Nil	4.2	Nil	1.9	Nil	1.1	Nil
41	$NaHCO_3$	Na equiv. to Na in pot 35	16.2	Nil	4.1	Nil	0.7	Nil	2.0	Nil
Soil Characteristics:										
Colloid content, %			64.0		45.0		22.5		71.0	
SiO_2/R_2O_3 of colloid			2.3		1.37		1.16		2.38	
pH values			4.9		5.1		4.8		7.1	
Total base exch. cap. of soil			17.3		5.28		7.43		Contains free $CaCO_3$	
Total P_2O_5 cont., lbs. per acre			1,294		1,443		398		2,838	

*Each pot received nitrogen and potassium fertilization.

†The rates of applications were on the basis of equivalent units of material per unit of colloid instead of units of material per acre, thus a rate of 1,000 lbs. per acre to the Eutaw with a 64% colloid content would be 700, 445, and 1,110 lbs. per acre to the Cecil, Norfolk, and Sumter soils with 45, 22.5, and 71% colloid contents, respectively.

It is interesting and significant that the silicates were effective only in the Eutaw clay. Of the acid soils in this group, the Eutaw clay has the highest silica-sesquioxide ratio, 2.3; thus, its iron content is low in respect to its silicate content. In this sense, it represents more nearly the low-iron alumino-silicate colloid used in the laboratory than either of the other acid soils. In the high-iron colloid in the laboratory, the iron played the principal rôle in retaining the phosphate at the most acid reactions, and one would not expect a phosphate anion of precipitated iron phosphates to be as readily replaced by a silicate anion as when the phosphate anion was sorbed by some surface valences of a colloid. The colloidal fraction of the Cecil and Norfolk soils resemble the high-iron colloid used in the laboratory. In these soils, the free iron content is high in respect to the silicate content; note the silica-sesquioxide ratios of 1.37 for the Cecil and 1.16 for the Norfolk. The content of alumino-silicate complex of the Cecil and the Norfolk is low with respect to that of the Eutaw as indicated by the total exchangeable base capacities of the soils, which are 5.28, 7.43, and 17.3, respectively. (The higher value for the Norfolk fine sandy loam than for the Cecil clay is accounted for by the fact that the Norfolk was taken from a virgin area and contained more organic matter than the Cecil.) The relative abundance of an alumino-silicate complex is important as it was shown in the laboratory investigations that it plays an active part in phosphate retention in acid systems where the free iron content is low.

It is also of interest to note that the growth made on the soils that did not receive any phosphorus (pot No. 3) was 7.5, 1.1, and 2.0 grams on the Eutaw, Cecil, and Norfolk, respectively. This again agrees with the interpretation of the data from the colloidal systems used in the laboratory. The native phosphorus in the Eutaw clay, where the silica-sesquioxide ratio was high, was more available than that in the Cecil and Norfolk soils with low silica-sesquioxide ratios. This was shown by the differences in the growth made by plants on the three soils when phosphorus was not added.

The results with the Sumter clay, a soil that contains an abundance of free $CaCO_3$, show no benefits from the silicates, except in the case where the sodium silicate had been added at the rate of 2 tons per acre. Here the presence of sodium ions with the calcium ions would explain the results in that the sodium formed some soluble sodium phosphates from the calcium phosphates in the soil. This soil contains more natural phosphate than any of the soils in the experiment. This soil is comparable to the low-iron colloids containing an excess of $CaCO_3$ which fixed all the phosphate added.

DISCUSSION

MECHANISM OF PHOSPHATE RETENTION

If the data for the Na-series of Fig. 3 are plotted to show the relation between the amount of phosphate ions sorbed by the colloid and the amount of phosphate ions in solution at the pH value where the maximum sorption occurred, a curve as shown in Fig. 7 is obtained. This curve shows that this alumino-silicate colloid has a sorption capacity of 10 millimols of PO_4 or 30 M. E. of anions per 100 grams of the colloid. In Fig. 1 it appears that the cation sorption capacity of this colloid is about 100 M. E. per 100 grams, thus the anion sorption capacity of the colloid in the presence of a monovalent cation, Na, is approximately one-third of the cation sorption capacity.

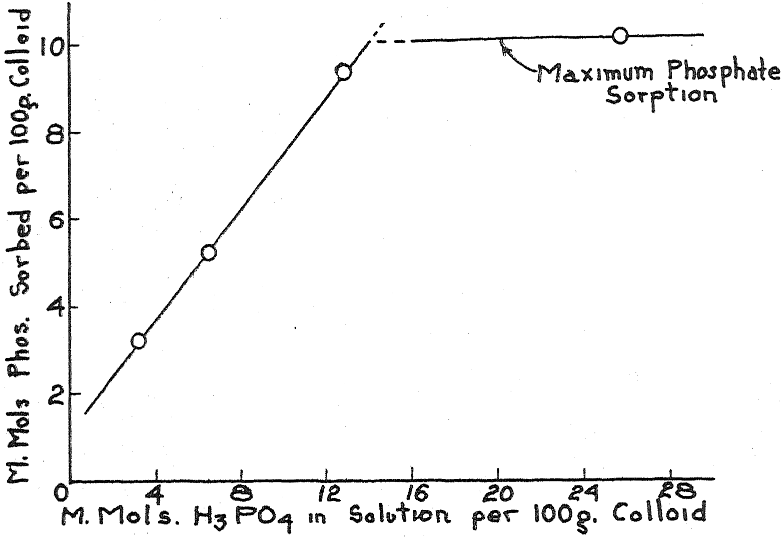

FIG. 7.—The relation between the concentration of phosphate ions in solution and the amount of phosphate ions retained by the low-iron content alumino-silicate colloid at pH 6.0 in the presence of sodium ions. The maximum phosphate capacity (anion sorption capacity) of the colloid in the presence of a mono-valent cation (Na) appears to be 10 millimols of PO_4^{---} or 30 milliequivalents of anions per 100 grams of the colloid.

It will be noted in Fig. 3 that the maximum deflection in the curve for the highest phosphate rate in the Ca-series occurs farther up on the graph than in the case with the Na-series. (It is apparent that the maximum sorption capacity for the alumino-silicate complex cannot be measured by the present method when a divalent cation is sorbed by the complex.) This indicates that the phosphate is also held by one of the valences of the calcium as the latter shares its two valences with the phosphate anion and the complex. These evidences form the basis for the writer's concept of the mechanism involved in the retention of phosphates by the colloidal systems studied; this concept is set forth in a series of idealistic diagrams in Fig. 8.

The atomic structure of the alumino-silicate complex is hypothetical, as pointed out by Brown and Byers (5), but it serves to express the chemical relationships that exist on the surface of the colloids. The silica-alumina ratio of the tested colloid was 4.5. This ratio in the diagrams is 4.0. The difference could easily be accounted for as free silica in the bentonite colloid. The cation-anion ratio in the diagrams is made to be 3.0; for the tested colloid it was 3.03. The H symbols represent exchangeable hydrogen or cation valences and the symbol X represents a continuation of the alumino-silicate complex into the colloidal crystal.

At pH 6.0, when the cation valences of the complex are practically saturated with hydrogen, the PO_4 anions are not sorbed. (See Fig. 3.) The anion valences must be satisfied with OH anions which are held with a very great electrostatic force since here the hydroxyl anions are not dissociated. The PO_4 ions will remain in solution unless the environment contains iron, in which case insoluble iron phosphates are formed. (See Fig. 4.)

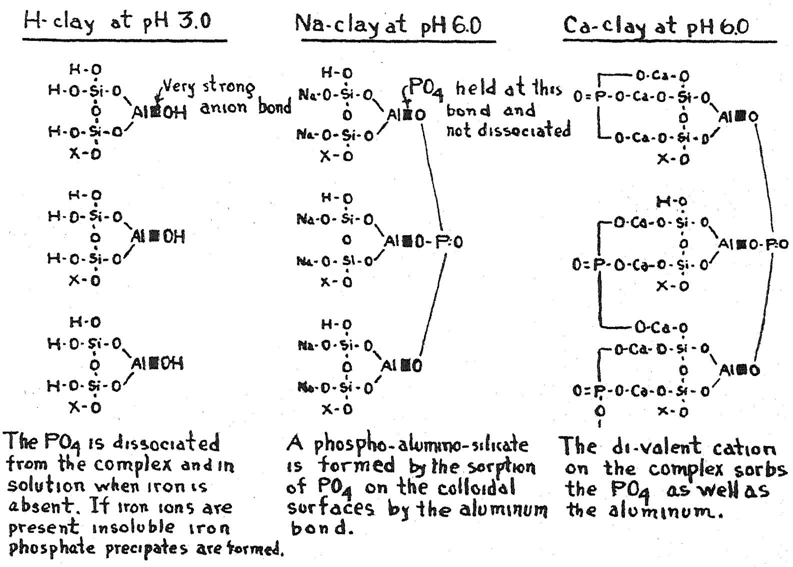
H-clay at pH 3.0
Na-clay at pH 6.0
Ca-clay at pH 6.0
Very strong anion bond
PO4 held at this bond and not dissociated
The PO4 is dissociated from the complex and in solution when iron is absent. If iron ions are present insoluble iron phosphate precipates are formed.
A phospho-alumino-silicate is formed by the sorption of PO4 on the colloidal surfaces by the aluminum bond.
The di-valent cation on the complex sorbs the PO4 as well as the aluminum.

FIG. 8.—Diagrams of the apparent mechanism of phosphate retention by the alumino-silicate colloid when unsaturated or partially saturated with sodium or calcium. X represents the continuation of the alumino-silicate complex into the colloidal crystal.

At pH 6.0, when the complex is partially saturated with Na, the aluminum bond of the colloidal complex sorbs the PO_4 anion. This extremely complex colloid can be thought of as an alumino-phosphosilicate. Since the cation is mono-valent and thus has no residual bond for other anions, and since any sodium phosphate that may be formed is soluble, it follows that the retention of the phosphate can be only by the colloid. Gaarder (7) has shown that the maximum insolubility of the phosphate anions occurs at a pH between 5.0 and 6.0 when there is an excess of aluminum present, and the basic ion present is Na. Thus, the evidence indicates that it is the aluminum valences in the surfaces of the colloid that retains the PO_4 in the low-iron colloids used. In normal soils free $Al(OH)_3$ would also retain phosphates.

At pH 6.0, when the complex is partially saturated with Ca, the PO_4 is retained by the aluminum bond as in the case with the Na-clay, but, as is shown in Fig. 3, the sorption capacity is greater when the cation on the complex is di-valent than when it is mono-valent. The greater sorption capacity by the Ca-clay appears to be caused by the retention of the phosphate by the Ca that is sorbed on the complex.

The data do not clearly indicate whether the phosphate is sorbed as a mono-, di-, or tri-valent anion. The investigations of Steele (18), which have been conducted in close coordination with the present study, indicate that the phosphate is sorbed by clays as the tri-valent anion.

At the higher pH values the PO_4 retained by the colloid complex is replaced by the OH anion. This was proved earlier in this paper and is evident in the curves of Fig. 3. If the basic ions are Ca, the PO_4 ions replaced by the OH are precipitated as insoluble calcium phosphates. When the colloid systems contain free $CaCO_3$, all of the PO_4 ions are precipitated.

This concept of the mechanism of the retention of phosphates by the alumino-silicate colloid is essentially in agreement with the results of Ungerer and Bradfield. Ungerer (19, 20) showed that K-permutite and NH_4-permutite increased the amount of P_2O_5 in solution when the permutites were added to the insoluble phosphates of lithium, magnesium, calcium, strontium, and barium. Bradfield (3) found that SO_4 and C_2O_4 anions of such insoluble salts as $BaSO_4$ and CaC_2O_4 were brought into solution in appreciable amounts by a Na-clay (bentonite) and that the exchanged cations were retained by the clay. Their results can be explained as a double decomposition reaction with the formation of a more soluble phosphate from ionic exchange.

RELATION OF PHOSPHATE SOLUBILITY TO LIMING INJURY

It has been pointed out that changing the reaction of soils having a colloidal fraction with a high silica-sesquioxide ratio from very acid (pH 3.0 to 5.0) to slightly acid (pH 6.0) will cause a depression in the amount of soluble phosphorus. This depression is caused by bringing the reaction to the point where the alumino-silicate complex exerts its maximum phosphate-sorption tendency. This fact is proved in the Ca-series (Fig. 3) and is demonstrated (Fig. 9) by the yields of oats on a heavy clay soil that had a silica-sesquioxide ratio of 2.3 for its colloidal fraction. It will be noted in Fig. 9 that liming the soil to pH 6.0 caused a great depression in the plant growth when the amount of available phosphate supplied was relatively low. When the available phosphate level was high, as represented by the greatest rate of application of the phosphate fertilizers, liming the soil to pH 6.0 did not decrease the yield; on the contrary, it increased the yield. Other investigations by the author (15) have shown that over-liming the soil to the extent that it contains free $CaCO_3$ after all the soil acids have been neutralized causes a great deficiency in the available phosphate. The injury from over-liming tends to be

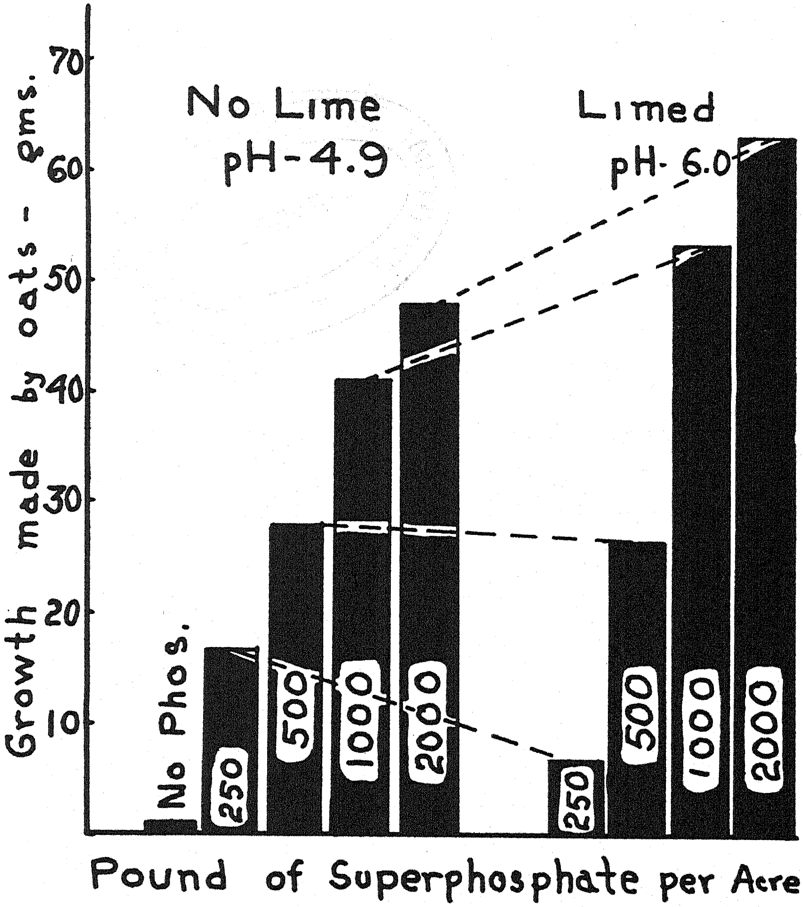

FIG. 9.—The growth made by oats in greenhouse test pots on a 60% colloid content soil that has a high silica-sesquioxide ratio (2.3) where various levels of soluble phosphate have been applied without lime and with lime. The lime depressed the growth where the amount of applied phosphate was low and increased the growth where the amount of applied phosphate was high.

somewhat temporary and becomes less as the soil solution becomes less alkaline. It is important to recognize the differences involved in respect to the relationship of the behavior of the phosphates to the injury from liming, since in one case the injury results merely from changing the reaction and in the other case from the presence of free carbonates.

PRACTICAL ASPECTS OF ANION EXCHANGE

The fact that the native unavailable phosphates in certain soils can be replaced by other anions presents a practical approach to the problem of maintaining a high level of available phosphorus in heavy clay soils that have a colloidal fraction with a high silica-sesquioxide ratio. It may be practical to add silicates to such soils; also it may be that the addition of blast furnace slag, which is a calcium silicate, to mixed fertilizers as a filler may have some advantages in increasing the availability of the natural soil phosphates and in retarding the rate of fixation of the applied phosphate. Other commercial forms of silicates may be found valuable in this connection.

The benefits derived from organic matter may be attributed in part to the humates replacing phosphates since the humates are anions that may be sorbed similarly to the phosphate anions.

It is apparent that in order to apply the principles set forth in this investigation to normal soils it is necessary to have considerable information on the fundamental characteristics of the soil colloids.

SUMMARY

The colloidal clay fraction of a natural alumino-silicate (bentonite) was freed from all mobile ions by electrodialysis and made into 16 series of 0.8% suspensions with eight individual treatments in each series. The concentrations of phosphate, sodium, calcium, and hydroxyl ions were varied systematically. At equilibrium, tests were made to determine the amount of phosphate ions retained by the colloids, the pH values, and the conductivity of the different systems both before carbonation and after carbonation when equilibrium with the CO_2 of the air was attained.

The alumino-silicate colloid was found to sorb the phosphate ions. Maximum retention occurred between pH 5.2 and 6.1 when Ca ions were the exchangeable cations present and at about pH 6.1 when Na ions were present. The anion sorption capacity in the presence of the Na ions was found to be approximately one-third of the cation sorption capacity. The Ca ions greatly increased the phosphate sorption capacity of the colloidal complex in the acid range. At the point where the cation valences were saturated with Ca ions (pH 8.2) the concentration of phosphate ions in solution decreased as the concentration of the unsorbed Ca ions increased, due to the formation of insoluble calcium phosphates. All the phosphate was insoluble when the system contained free $CaCO_3$. No insoluble phosphates were formed at the high pH values when Na ions were the cations used.

The phosphate retained at the pH values of 5.5 to 6.1 is believed to be sorbed on the colloidal surfaces of the alumino-silicate by the aluminum valence. The phosphate ion was found to be exchangeable and was replaced by OH and SiO_4 anions.

The retention of the phosphate ion by the colloid was greatly increased when the alumino-silicate was enriched with iron. With Ca on the clay complex and after the systems that received 25.8 millimols of H_3PO_4 per 100 grams of colloid had been carbonated, the minimum retention occurred between pH 4.0 and 5.5. The formation of $Fe_2(CO_3)_3$ from the carbonation treatment lowered the concentration of iron ions, thus permitting a greater amount of phosphate ions to remain in solution. The maximum retention occurred at pH

3.0 where insoluble iron phosphates were formed and at pH values above 8.0 where insoluble calcium phosphates were formed in the presence of $CaCO_3$. This would indicate that injury from "overliming" may be caused by a deficiency in available phosphates to the plant.

The data show that plant injury from light applications of lime is caused by a decrease in the availability of the phosphate and is likely to occur only in soils relatively low in sesquioxides. Changing the pH from 4.0 to between 5.5 and 6.2 caused all the phosphate to be retained by the low-iron colloid when the amount of phosphate added to the system was relatively small; but when the amount of phosphate added was large, the retention was not nearly complete.

The phenomenon of the replacement of the phosphate anion from the alumino-silicate colloidal systems by the silicate anion as found in the laboratory studies was verified with four soils in greenhouse pot tests with sorghum plants. The most outstanding phosphate replacement resulted on a very acid, heavy clay soil with a silica-sesquioxide ratio of 2.3, where sodium silicate produced a growth without a phosphatic fertilizer almost equal to that on the phosphate-fertilized soil.

A concept of the mechanism of the retention of phosphates by soil colloids is set forth and some practical aspects of anion exchange are suggested.

LITERATURE CITED

1. Benedict, S. R., and Theis, R. C. A modification of the molybdic method for the determination of inorganic phosphorus in serum. Jour. Biol. Chem., 61 : 63–66. 1924.
2. Bradfield, Richard. The colloidal chemistry of soils. Colloid Chemistry, by Alexander. New York : The Chemical Catalog Co. Inc. 1931. (Vol. 3, pages 569–590.)
3. ———. The concentration of cations in clay soils. Jour. Phy. Chem., 36 : 340–347. 1932.
4. ——— and Allison, W. B. Criteria of base saturation in soils. Trans. Int. Soc. Soil Sci., A : 63–79. 1933.
5. Brown, I. C., and Byers, H. G. The fractionation, composition, and hypothetical constitution of certain colloids derived from the Great Soil Group. U. S. D. A. Tech. Bul. 319. 1932.
6. Demolon, A. Fixation and exchange of certain anions by soil colloids. Mezogazdasagi Kutatasok, 6 : 474–479. 1933.
7. Gaarder, Torbjorn. Die Bindung der Phosphorsaure im Erd Boden. Vestlandets Forstlige Forsoksstation, Meddelelse Nr. 14, Bergen. 1930.
8. Mattson, Sante, and Pugh, A. J. The laws of soil colloidal behavior: XIV. The electrokinetics of hydrous oxides and their ionic exchange. Soil Science, 38 : 299–313. 1934.
9. ———. The laws of soil colloidal behavior: VI. Amphoteric behavior. Soil Science, 32 : 343–365. 1931.
10. Naftel, J. A. The glass electrode and its application in soil acidity determinations. Soil Res., 4 : 41–50. 1934.
11. Pugh, A. J. Laws of soil colloidal behavior : III. Colloidal phosphates. Soil Science, 38 : 315–334. 1934.
12. Ravikovitch, S. Anion exchange : I. Absorption of the phosphoric acid ions by soils. Soil Science, 38 : 219–239. 1934.
13. Roszman, C. A. Retention of phosphates by soil colloids. Soil Science, 24 : 465–474. 1927.
14. Scarseth, George D. Morphological, greenhouse, and chemical studies of the Black Belt soils of Alabama. Ala. Agr. Exp. Sta. Bul. 237. 1932.

15. ———— and TIDMORE, J. W. The fixation of phosphates by clay soils. Jour. Amer. Soc. Agron., 26 : 152–162. 1934.
16. ————, ————. The fixation of phosphates by soil colloids. Jour. Amer. Soc. Agron., 26 : 138–152. 1934.
17. SCHOLLENBERGER, C. J. Silica and silicates in relation to plant growth and composition. Soil Science, 14 : 347–362. 1922.
18. STEELE, J. G. The effect of other anions on the retention of phosphates by colloidal clays. Unpublished thesis, Ohio State Univ. 1934.
19. UNGERER, E. Austauschreaktionen wasserunloslicher Erdalkaliphosphate mit Permutiten und Tonen. Koll. Zeit., B. 48, H. 3. 1929.
20. ————. Austauschreaktionen schwerloslicher Phosphate und Sulfate mit Permutiten. Koll. Zeit., B. 52, H. 2. 1930.

LOCAL VARIABILITY IN THE PHYSICAL COMPOSITION OF WISCONSIN DRIFT[1]

Eric Winters and Herman Wascher[2]

During the course of the soil survey of Ford and Vermilion counties, Illinois, in 1929 and 1930, marked differences were noted in the character of the unleached glacial drift; differences which could not be explained as being due to separate and distinct glacial advances because they did not coincide with the morainal lines. Moreover, within a given area the depth to unleached material appeared to be governed, not by any possible difference in age, but by variations in the permeability of the drift.

Field observations indicated that soil types correlated with the variations in the character of the parent glacial till. According to Marbut (3)[3] and others, parent material is of minor importance in soil classification after the climatic forces of weathering have acted a sufficient time to impress those features, which they are capable of impressing, on the soil profile. However, in a geologically young region such as that part of northeastern Illinois covered by the Wisconsin drift sheet, the character of the parent material has had a strong influence on the character of the soils developed from it. In the region studied, free carbonates occur at 2 to 4 feet below the surface and their presence at this depth indicates that here the parent material is still exerting a strong influence in the soil profile and will continue to be of major importance in its development for a long time. Subdrainage and the effectiveness of tile in this region depend in a large measure on the permeability of the unleached drift substratum, consequently the agricultural value of the land is largely dependent on the character of this underlying drift.

The significance of this conclusion is emphasized by the data of Stauffer (5) which show that the physical properties of the soil profile are closely correlated with the properties of the underlying drift. Krumbein (1) analysed samples of till from several areas of the Wisconsin advance and his data also show marked variations in drift composition. He pointed out that certain regional drift separations probably could be made, but neither he nor Stauffer attempted to outline the local distribution of the several types of drift.

Little other accurate data on the mechanical composition of glacial drift are available. Results obtained by the older sedimentation methods are of limited value because dispersion, particularly of the clay, was variable and incomplete.

PROCEDURE

The northwest portion of Vermilion County, Ill., is a region in which the drift is very heterogeneous and this area was chosen for intensive study. Numerous

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[2] Assistant and First Assistant, respectively.

[3] Reference by number is to "Literature Cited," p. 622.

sections were examined in the field in an attempt to separate the drift into groups by the handling properties, such as plasticity and compaction. Under varying moisture conditions this proved difficult, particularly without type sections of known properties for reference. Therefore, to supplement the field work, samples for mechanical analysis were taken with a spade, as outlined by Krumbein (1) and as practiced by the Illinois Soil Survey for many years, from certain sections thought to be representative, as well as from others of doubtful and unusual character. In all cases the material represents calcareous till and lies within the D horizon as defined by Norton and Smith (4). This corresponds to horizon 4 in the terminology of Leighton and MacClintock (2), and in this region lies at an average depth of 3 feet.

The method of Winters and Harland (6), omitting the HCl pretreatment, was used in making the mechanical analyses, the results of which are reported in Table 1. Since these samples contained very little material larger than 2 mm and in some cases none at all, coarse gravel has been neglected in calculating the percentages. Silt (0.05 to 0.005 mm) is not reported, but may be found by taking the difference between 100% and the sum of the sand and clay fractions. The figures in column 2, which give the approximate free carbonate content, were calculated from the carbon dioxide evolution in terms of calcium carbonate equivalent.

DISCUSSION

In Table 1 the data are arranged in ascending order of the content of colloidal material. The trend of the sand content thus becomes, in general, descending with an occasional exception, but these deviations are hardly large enough to be of importance. The free carbonates fall in most cases between 18 and 25%, showing that these samples are relatively unleached and unweathered as mentioned above. Those cases where the carbonates are low might be interpreted as resulting from partial leaching, or else the original sediments may have been less calcareous. The fact that the low carbonate samples are usually high in colloids lends probability to the latter suggestion.

It is clear that no till groups can be defined merely by an inspection of the data in Table 1. In fact the variation from sample to sample is so gradual and regular that the impression is one of a continuous series rather than definite groups. Perhaps such a situation might be expected from a knowledge of the origin of drift. The variation in the surficial material and the lack of uniformity in the degree of grinding and mixing by the glacier must have presented the possibilities for a resulting drift of almost any imaginable composition.

To help judge the significance of the data in regard to the rate of percolation of water, it will be helpful to compare them with the analyses of soil horizons whose permeability is known. Impermeable subsoils of Putnam silt loam from southern Illinois have been examined and none show more than 55% clay; in fact, few exceed 50%. Their colloid content, however, runs from 38 to 43%, though it must be said that the base saturation is low, indicating a highly dispersed condition. The rather slowly permeable subsoils of Grundy silt loam from west-central Illinois are saturated with bases, these horizons containing 45 to 48% clay and 35 to 37% colloids.

It will be noted that the colloidal contents in Table 1 approximate one-half the clay percentages, a relationship that also holds in surface soils which have undergone considerable eluviation. In illuviated and in less strongly eluviated soil horizons, the colloids usually account for two-thirds or more of the clay. The suggestion is offered that this is so because glacial action was severe enough in the region under discussion to pulverize many of the sedimentary rocks to clay size, but that colloids originate chiefly through chemical weathering. Therefore, somewhat different criteria must be used

TABLE 1.—*Mechanical analysis of Wisconsin drifts in Vermilion County, Ill.*

Sample No.	$CaCO_3$ equivalent %	Mechanical analysis		
		Sand, 2.0–0.05 mm, %	Clay, 0.005 mm, %	Colloid, 0.001 mm, %
		Elliott		
1	23.2	17.7	37.4	18.2
2	24.5	12.4	35.6	18.5
3	19.6	16.3	38.0	20.0
4	24.5	7.4	47.0	22.8
5	22.3	15.0	45.8	23.1
6	23.2	11.2	50.0	24.2
7	25.0	7.9	51.0	25.0
8	20.5	7.6	49.8	25.3
9	22.8	8.6	51.4	26.2
10	19.6	8.4	51.5	26.4
		Plastic Elliott		
11	21.9	7.3	53.0	27.3
12	27.6	7.4	50.8	27.6
13	22.0	5.2	54.4	27.8
14	22.4	5.4	51.1	28.1
15	21.6	2.2	56.5	29.1
16	21.4	7.1	56.2	29.2
17	23.4	8.8	55.2	29.4
18	20.0	7.8	56.4	30.4
19	22.9	7.6	62.3	30.6
20	—*	7.4	57.8	30.0
21	22.3	7.6	58.4	31.3
22	23.6	7.3	58.2	31.6
23	12.0	7.2	59.1	31.8
		Clarence		
24	18.4	6.2	61.5	32.8
25	21.7	5.9	64.0	33.8
26	21.0	5.5	63.0	34.8
27	18.9	5.2	70.8	35.6
28	21.4	5.2	65.8	35.8
29	21.5	5.2	66.0	35.8
30	19.5	4.8	68.2	38.1
31	—*	4.7	70.7	41.2
32	—*	2.2	76.2	41.6
33	19.5	2.3	78.8	42.4
34	6.2	3.1	74.0	43.7
35	16.7	3.5	80.3	43.7
36	11.4	3.2	80.5	54.5

*Not determined.

in judging the permeability of till on the basis of mechanical analyses than are applied to most soil horizons since the ratio of colloid to clay is so different. Observations were made in the field at the various sampling localities of the drainage characteristics of the till and the overlying soil. Bringing all the evidence together, it seems reasonable to expect that a clay content of 50% or more will be associated with rather slow percolation in this region. As the clay reaches 65 to 70%, the colloid usually is about 35% and percolation becomes extremely slow, in fact quite comparable to the southern Illinois subsoils mentioned above.

Sand does not seem important in affecting permeability until it exceeds at least 10%, hence it is seldom of concern in the profiles high in clay content. However, when the clay falls below 40%, as with the samples at the top of Table 1, some attention must be paid to sand. Thus, the first three samples are approaching moderate permeability.

Combining field observation and laboratory data, four groups of till have been set up and are defined as follows:

1. Clarence—Impermeable, plastic..........	Clay	> 60–65%
	Colloid	> 34–31%
2. Plastic Elliott—Slowly permeable, plastic..	Clay	> 50–54%
	Colloid	> 28–26%
3. Elliott—Slow to moderate permeability....	Clay	> 36–38%
	Colloid	> 18–16%
4. Saybrook—Permeable..................	Clay	< 36–38%
	Colloid	< 18–16%
	Sand	> 15%

No samples of Saybrook are included in Table 1, though the first three are approaching this group in properties.

The groups exhibit color differences as well as differences in plasticity which are helpful in field identification. Clarence is invariably gray, while Saybrook is distinctly yellowish[4] and this, in conjunction with the associated plasticity and textural properties, make these two groups very distinctive. As might be expected, the color grades gradually through the Elliott groups just as do the clay contents.

Sample No. 36 in Table 1 is worthy of special attention. It is from a layer of plastic material about 2 feet in thickness having calcareous Elliott both above and below. It is exposed in a road cut near Armstrong and is very conspicuous. Its low carbonate content in view of the absence of any possibility for leaching strengthens the suggestion previously made that Clarence often may be low in limestone and high in shale compared to Elliott.

The location of the samples in Vermilion County is given by number in Fig. 1. The outlines of each group as determined by a rather

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[4] Saybrook drift in the western part of the Wisconsin area is pink tinged.

detailed field survey, using the laboratory data as a guide, are also indicated. The areas are neither continuous nor abruptly demarked. This may be interpreted to mean that all the drift of the region belongs to the same glacial advance and varies little if any in age. Some samples appear to be within the wrong boundaries according to their analyses (Nos. 6, 8, and 19, for example), but this results from the occurrence of sharp local variations. Attention is called to Nos. 2 and 32 located close together yet extremely different in composition. The difficulty of placing the intermediate samples as Nos. 6 and 8 in the right group is often considerable and emphasizes the fact already pointed out that local variations within the drift do occur and that the drift groupings must often be more or less arbitrary.

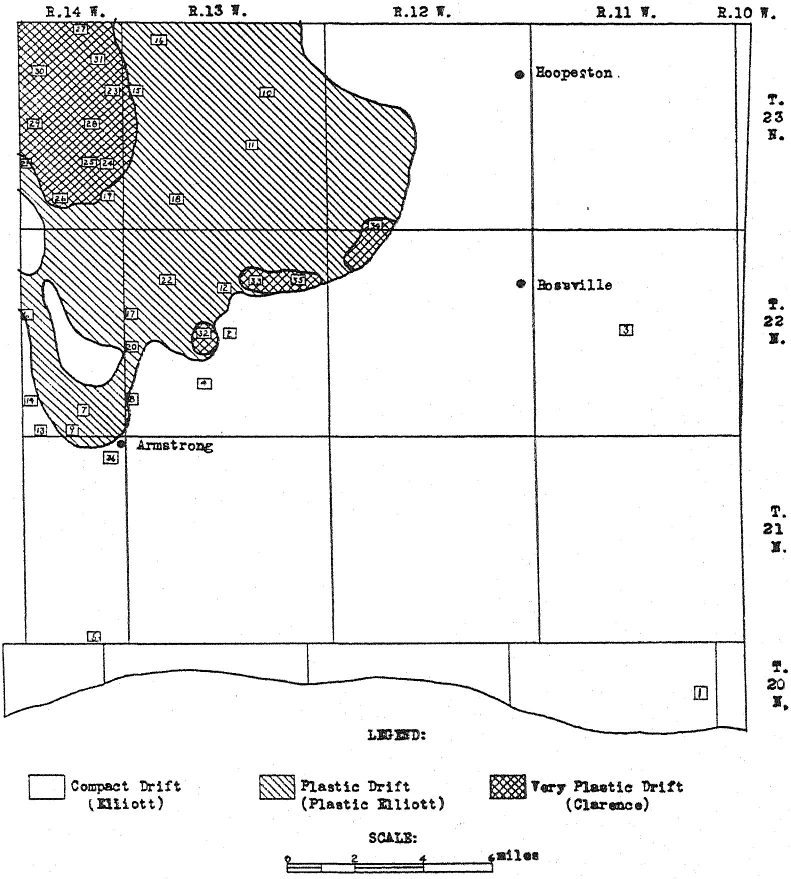

FIG. 1.—Northern portion of Vermilion County, Illinois, showing distribution of drift groups.

The practical significance of these arbitrary groupings might be questioned. Since this study was started the field work of the Soil

Survey has included counties in other parts of the Wisconsin drift area. This work, which will be reported on in detail in a later paper, has indicated that erosion is less destructive, tile are more effective, and crop yields are higher on soils developed from so-called Saybrook drift than those developed from so-called Elliott drift when considered under the same conditions of topography and native vegetation. Similarly, soils developed from Elliott are more desirable than those developed from Plastic Elliott and Clarence drift. Thus, the major soil divisions of the region have come to be based upon the physical composition of the drift from which the soil is developing as this has proved the most usable criterion in making regional separations.

SUMMARY

Mechanical analyses for 36 samples of glacial till are presented which show the wide range in physical composition of Wisconsin drift within a small area. Using these analyses in conjunction with field observations, four till groups have been defined whose properties are different enough to form the basis for soil series separation in the region.

LITERATURE CITED

1. Krumbein, W. C. Textural and lithological variations in glacial till. Jour. Geol., 41 : 382. 1933.
2. Leighton, M. M., and MacClintock, Paul. Weathered zones of the drift sheets of Illinois. Jour. Geol., 38 : 28. 1930.
3. Marbut, C. F. A scheme for soil classification. Proc. First Int. Cong. Soil Sci., 4 : 1. 1928.
4. Norton, E. A., and Smith, R. S. Horizons designations. Amer. Soil Survey Assoc. Bul., 9 : 83. 1928.
5. Stauffer, R. S. Unpublished data.
6. Winters, E., and Harland, M. B. Preparation of soil samples for pipette analysis. Jour. Amer. Soc. Agron., 22 : 771. 1930.

NON-ACID-FORMING MIXED FERTILIZERS: I. THEIR EFFECT ON CERTAIN CHEMICAL AND BIOLOGICAL CHANGES IN THE SOIL-FERTILIZER ZONE AND ON PLANT GROWTH[1]

J. R. Taylor, Jr., and W. H. Pierre[2]

THE problem of fertilizer acidity has become of increasing importance in recent years. Although the general problem has received considerable study, new questions have arisen as a result of the rapidly increasing use of dolomitic limestone in the production of non-acid-forming fertilizers and the tendency to concentrate the fertilizer in narrow bands along the row. Foremost among these is the effect of potentially neutral fertilizers containing dolomitic limestone supplements on chemical and biological changes in the zone of fertilizer incorporation and the resulting effect upon plant growth.

In general, dolomitic limestone supplements have been considered to be beneficial in two respects, *viz.*, (a) the dolomitic limestone is valuable in neutralizing the acidity produced in the soil by the fertilizer, and (b) it supplies magnesium, an element that in recent years has been found to be deficient in certain soils of the eastern states. In addition to these two functions it is possible, as some of the data obtained in this investigation indicate, that dolomitic limestone supplements may be valuable in other respects.

Although the amounts of limestone added to the soil through the use of non-acid-forming fertilizers are low on the acre basis, it should be recognized that the concentration of limestone in the zone of fertilizer incorporation is high in many cases. This may be expected to become increasingly true as a result of improvements in fertilizer distributing machinery and the tendency to concentrate the fertilizer in narrow bands along the row. Any changes in the soil in the fertilizer zone resulting from the presence of dolomitic limestone in the fertilizer would, therefore, be much greater when the fertilizer is applied in the row than when applied broadcast.

The purpose of this investigation was to compare the effects of acid-forming and potentially neutral fertilizers when added in concentrations comparable to those found in the soil-fertilizer zone under row or hill fertilization upon the following: (a) Nitrification of added ammonia; (b) pH value; (c) concentration of water-soluble magnesium, calcium, and phosphate; and (d) plant growth.

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[1] Contribution from the Department of Agronomy and Genetics, West Virginia Agricultural Experiment Station, Morgantown, W. Va. Published with the approval of the Director as Scientific Paper No. 151. Also presented before the Division of Fertilizer Chemistry at the Eighty-eighth meeting of the American Chemical Society, Cleveland, Ohio, September 10 to 14, 1934. Received for publication July 6, 1935.

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EXPERIMENT I. EFFECT OF ACID-FORMING AND POTENTIALLY NEUTRAL FERTILIZERS ON NITRATE PRODUCTION, H-ION CONCENTRATION, AND SOLUBLE MAGNESIUM IN UNCROPPED SOILS

METHOD OF PROCEDURE

A Dekalb silt loam soil of pH 4.85 and a Dekalb loam of pH 5.58 obtained from the Agronomy Farm were used in these studies. The two principal fertilizers used analyzed 6–8–6 and were made up with superphosphate as the source of phosphorus, muriate of potash as the source of potash, and urea and ammonium sulfate as sources of nitrogen. One-third of the nitrogen was from urea and two-thirds from ammonium sulfate; therefore, the equivalent acidity was 500 pounds $CaCO_3$ per ton. Sand was used as filler in the case of the acid-forming fertilizer and dolomitic limestone was used for the potentially neutral fertilizer. The dolomitic limestone analyzed 22.1% MgO and 30.9% CaO. It all passed through a 40-mesh sieve; 16.3% was held on a 60-mesh sieve, 14.0% on an 80-mesh sieve, 6.7% on a 100-mesh, and 63.0% went through a 100-mesh sieve. In addition to the two complete fertilizers, an 0–8–6 fertilizer carrying the same amount of superphosphate and muriate of potash as the former, but carrying no nitrogen nor dolomitic limestone, was used in order to serve as a check on the effect of the nitrogenous portion of the fertilizer.

The fertilizers were applied at such rates as to represent in a general way the concentrations of fertilizer in the zone of incorporation as obtained under common fertilizer application practices. Although such practices vary so widely that any rates selected must be considered arbitrary, it was possible to select what are believed to be reasonably representative values through a study of data kindly furnished by Dr. G. A. Cumings of the Bureau of Agricultural Engineering.[3]

The rates adopted were arrived at as follows: Acre applications of fertilizer are usually based on a weight of 2,000,000 pounds, which represents a volume of soil 6⅔ inches deep over an acre. In row fertilization, however, only a small part of the soil to a depth of 6⅔ inches is mixed with the fertilizer. With rows 36 inches apart, the total cross-sectional area for one row to a depth of 6⅔ inches is 240 square inches. Assuming the total cross-sectional area fertilized to be 5 to 20 square inches for potatoes, 10 to 15 square inches for cotton, and 2 to 10 square inches for corn, it is found that of the total cross-sectional area only the following portions are fertilized: 1/48 to 1/12 for potatoes, 1/24 to 1/16 for cotton, and 1/120 to 1/24 for corn. If acre rates of 1,000 pounds are taken for potatoes, 400 pounds for cotton, and 200 pounds for corn, the rate of fertilization on the basis of the fertilized zone would become 48,000 to 12,000 pounds per 2,000,000 pounds of soil for potatoes, 9,000 to 6,400 pounds for cotton, and 24,000 to 4,800 pounds for corn.

From a consideration of these values it was decided to use the different fertilizers on the Dekalb loam (No. 745) at the rates of 5,000 and 20,000 pounds per 2,000,000 pounds of soil and on the Dekalb silt loam (No. 744) at the rate of 20,000 pounds, these rates representing the concentration of fertilizer which may be found in the soil-fertilizer zone under average conditions. If it is assumed that in hill or row applications the fertilizer is mixed with only one-tenth of the surface 6⅔ inches of soil, the total amounts applied would correspond to 500 and 2,000 pounds per acre; if mixed with one-twentieth, to 250 and 1,000 pounds per acre, respectively. Hereafter, in this experiment the 5,000-pound application will be

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[3] Private communication.

referred to as the low rate of fertilization, and the 20,000 pounds as the high rate of fertilization.

The fertilizers were thoroughly mixed with separate 200-gram samples of each soil, the mixtures placed in small glass containers, and distilled water added to bring the soils to approximately optimum moisture content. The containers were then placed in an oven maintained at a constant temperature of 30° C. Distilled water was added from time to time to compensate for the amounts lost by exaporation. All treatments were in duplicate. After various intervals the soils were dried and samples removed for studies of pH, nitrification, and the concentration of water-soluble magnesium.

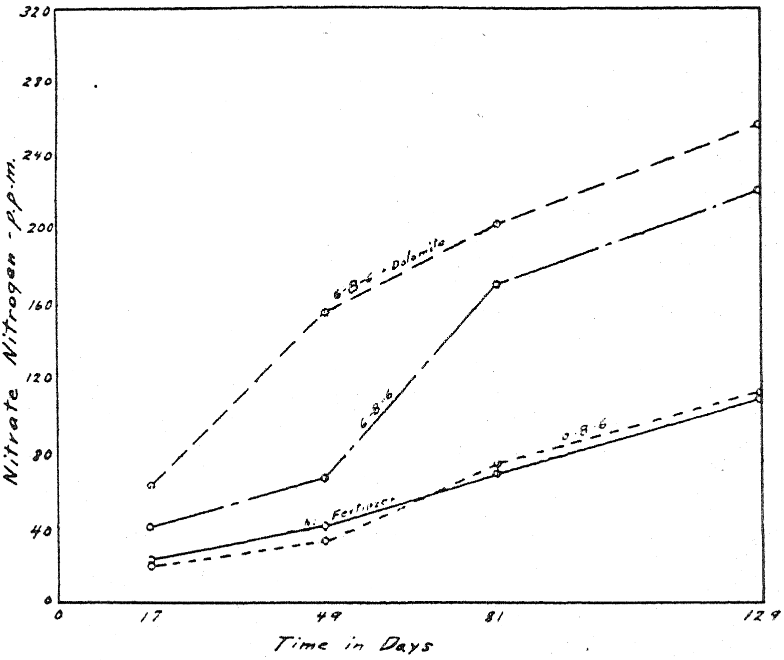

FIG. 1.—Nitrification in fertilizer zone after various intervals; soil 745, Dekalb loam; low rate of fertilization.

The water extracts of the soils were obtained by the dialysis method (8)[4] after the soil had been in contact with the water for 18 hours in the presence of sufficient toluene (1 cc per 125 cc water) to prevent denitrification. The pH was determined by the colorimetric method (8), nitrates by the phenoldisulfonic-acid method, and magnesium by the method described by Kramer and Tisdall (3).

EXPERIMENTAL RESULTS

Nitrate accumulation in the soil-fertilizer zone.—The amount of nitrates produced in the soil-fertilizer zone after various intervals is shown in Figs. 1 and 2 for the two rates of fertilization of the medium-acid Dekalb loam and in Fig. 3 for the high rate of fertilization of the strongly-acid Dekalb silt loam. In all cases it will be noted that the non-acid-forming fertilizer, which contained dolomitic limestone,

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[4] Figures in parenthesis refer to "Literature Cited," p. 641.

caused a much greater nitrification of the ammonia added than did the acid-forming fertilizer of similar analysis. This is especially noted

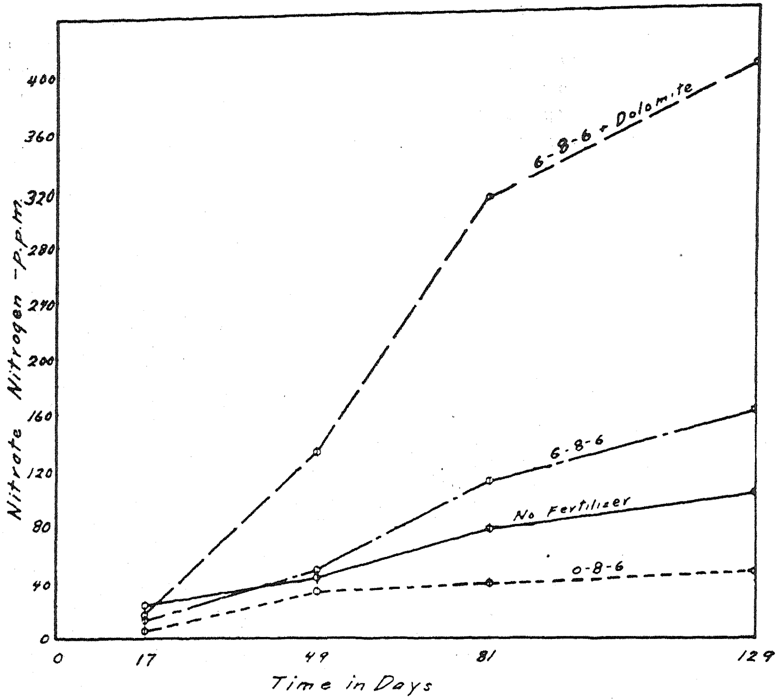

FIG. 2.—Nitrification in fertilizer zone after various intervals; soil 745, Dekalb loam; high rate of fertilization.

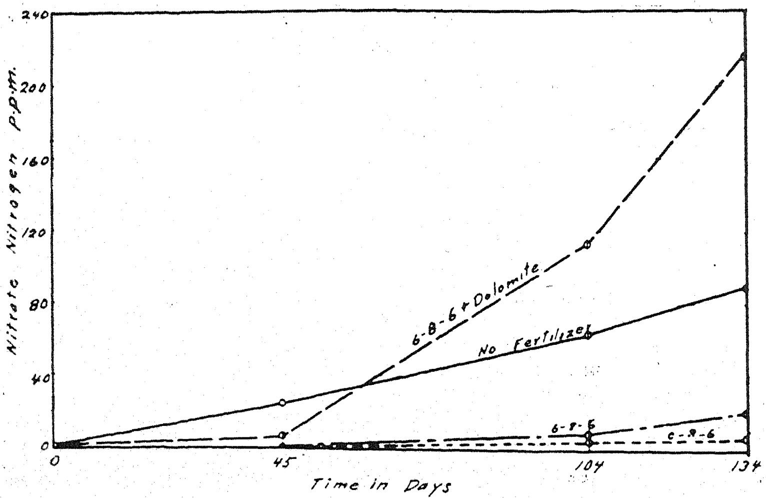

FIG. 3.—Nitrification in fertilizer zone after various intervals; soil 744, Dekalb silt loam; high rate of fertilization.

in Figs. 2 and 3 where the high rate of fertilization was used. The high salt concentration developed in the fertilizer zone from the high rate of fertilization inhibited nitrification on these acid soils. Thus, with both soils, the amount of nitrates produced was considerably lowered where the 0–8–6 fertilizer was used than where the soil received no treatment.

In Table 1 the data presented in the graphs are briefly summarized. The amounts of the added nitrogen which were nitrified after various intervals were calculated by subtracting the nitrates in the cultures receiving the 0–8–6 fertilizer from the nitrates present in the cultures receiving nitrogen in addition. As already noted in the graphs, the greatest difference in the nitrates produced where dolomitic limestone had and had not been added in the fertilizer was where the rate of fertilization was high and where the soil was the most acid. Thus, even after 122 days, only about one-fourth as much of the nitrogen added to soil 745 in the acid-forming fertilizer had nitrified as where the potentially neutral fertilizer was used; whereas with the more acid Dekalb silt loam (soil 744), less than one-fifteenth as much of the nitrogen was nitrified where the acid-forming fertilizer was used as where dolomitic limestone had been added to make the fertilizer potentially neutral. On less acid soils the difference in nitrification where acid-forming and where neutral fertilizers are added would, no doubt, be less.

TABLE 1.—*The effect of acid-forming and potentially neutral fertilizers on the nitrification of the ammonia in the fertilizer zone.**

Rate of fertilizer application, lbs. per acre†	Equivalent acidity of fertilizer (≈ lbs. $CaCO_3$ per ton)	Percentage of added ammonia nitrified			
		After 17 days	After 49 days	After 81 days	After 122 days
		Soil 745			
500	500	13.8	23.0	63.6	72.7
	0	28.4	77.8	92.2	96.4
2,000	500	1.2	5.2	12.0	12.1
	0	1.9	19.4	45.1	52.5
		Soil 744			
			After 45 days	After 104 days	After 134 days
2,000	500	—	0	0.5	2.3
	0	—	3.3	10.0	35.2

*6–8–6 fertilizer.

†On the basis of fertilizer zone. If it is assumed that the fertilizer zone represents 1/10 to 1/20 of the acre 6⅔ inches, the actual rates per acre would be 1/10 to 1/20 these amounts.

This important difference between the effects of acid-forming and potentially neutral fertilizers when applied to acid soils under certain conditions may be of considerable practical interest, for it has been shown by Tiedjens (10) and others (1, 2, 4, 11) that at low pH values and with some crops nitrate nitrogen is more readily utilized by plants than is ammonium nitrogen. Thus, the use of non-acid-forming fertilizers on very acid soils may, by promoting nitrification of the ammonia, cause the nitrogen of the fertilizer to be more available to plants.

pH in the soil-fertilizer zone after various intervals.—The pH values of the soil in the soil-fertilizer zone after various intervals are shown

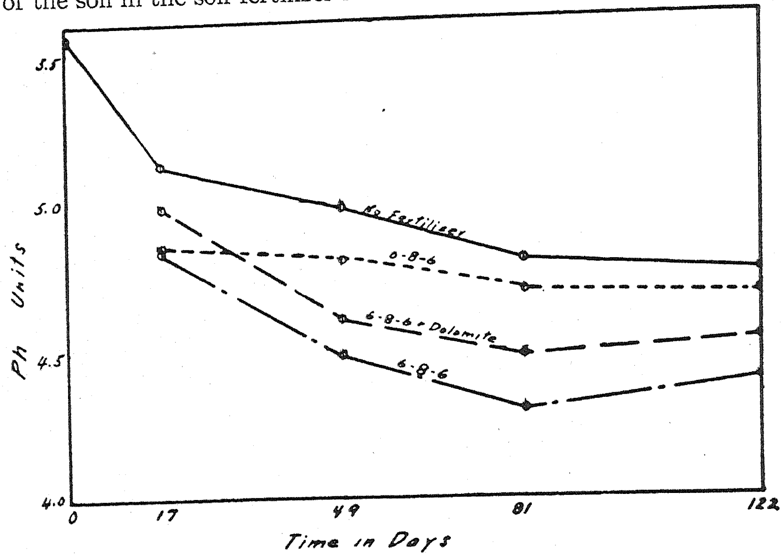

FIG. 4.—The pH of soil in fertilizer zone after various intervals; soil 745, Dekalb loam; low rate of fertilization.

in Figs. 4 and 5 for soil 745, and in Fig. 6 for soil 744. With the low rate of fertilizer application it will be seen from Fig. 4 that there was a rather rapid decrease in pH even where no fertilizer had been added. This is explained by the fact that the soil was removed from a sod area, and consequently the decomposition of some of the organic matter present and the production of nitrates (Fig. 1) took place rather rapidly. As would be expected, the cultures receiving the 0–8–6 fertilizer were lower in pH than the untreated ones, since an increase in salt concentration results in a temporary increase in hydrogen-ion concentration. The cultures receiving the 0–8–6 fertilizer, therefore, must be used as a standard in studying the effect of the complete fertilizer that is acid-forming and that which is potentially neutral. It will be noted that with the low rate of fertilization (Fig. 4) the complete fertilizer without dolomitic limestone caused a considerable increase in the acidity of the soil. The cultures which received the fertilizer containing dolomitic limestone had a slightly higher pH than those receiving the fertilizer without dolomite, but a lower pH than those receiving the 0–8–6 fertilizer. No doubt one of the reasons for the latter fact is that the dolomitic limestone did not decompose rapidly enough in this period of time to neutralize all the acidity formed from the rapid nitrification of the ammonia in the fertilizer.

In Fig. 5 are shown the data with the same soil but with a rate of fertilizer application four times as great. As was the case with the low rate of application series, the pH value of the soils receiving the 0–8–6 fertilizer and the "no fertilizer" treatment decreased rapidly during the first 17 days. Thereafter, the decrease was slower and in proportion to the decrease in nitrification (Fig. 2). With the complete fertilizer containing no dolomitic limestone, it is interesting to note that at the time of the first sampling the pH value of the soil was considerably higher than where the 0–8–6 fertilizer was used. This is no doubt explained by the fact that one-third of the nitrogen was derived from

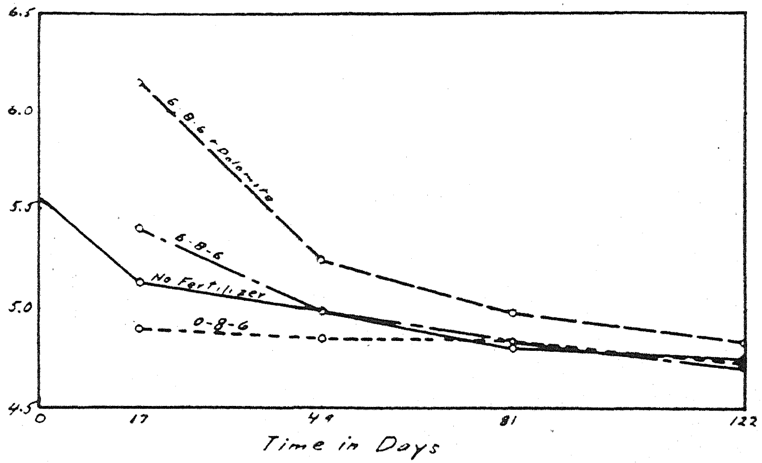

FIG. 5.—The pH of soil in fertilizer zone after various intervals; soil 745, Dekalb loam; high rate of fertilization.

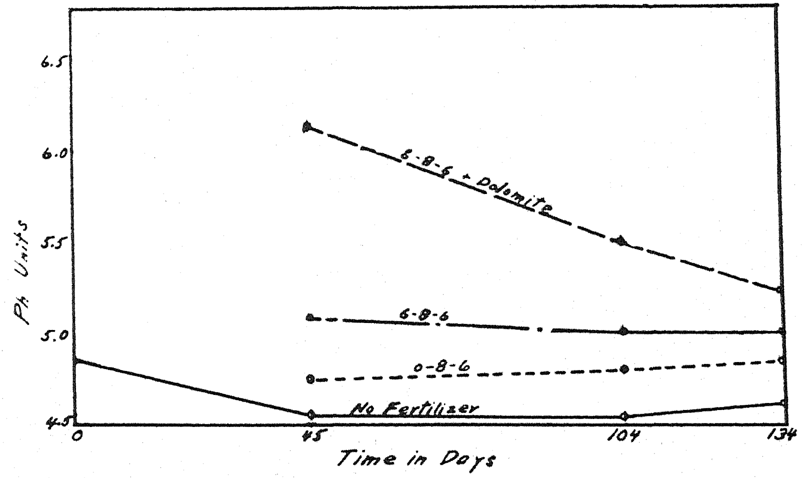

FIG. 6.—The pH of soil in fertilizer zone after various intervals; soil 744, Dekalb silt loam; high rate of fertilization.

urea and that before nitrification had taken place ammonium carbonate was being formed from the decomposition of urea. As shown in Fig. 2, nitrification was very slow where the acid-forming fertilizer was used. The potentially neutral fertilizer containing dolomitic limestone caused a rapid increase in pH, as shown by the data obtained after 17 days. This is due partly to the dolomitic limestone and partly to the temporary effect of the urea, previously described. After 17 days the pH value decreased rapidly. This is to be expected from the fact previously noted (Fig. 2) that there was a rapid increase in nitrification after this period.

At first thought it seems surprising that the dolomitic limestone supplement did not show a greater basic effect on the soil after the 49-day period. This is readily explained, however, by the fact that nitrification is an acidifying process and that the amount of nitrates produced was much greater where the neutral than where the acid-forming fertilizer was used. Thus, on the basis of the soil in the fertilizer zone it is found by calculation that approximately 2,900 pounds of calcium carbonate would be required per 2,000,000 pounds of soil to neutralize the acidity produced by the greater amount of nitrogen nitrified in the cultures receiving the dolomitic limestone-fertilizer mixture than in those receiving the sand-fertilizer mixture. This means that practically three-fifths of the limestone added was used in correcting the acidity produced by this greater nitrate formation. As the ammonia from the acid-forming fertilizer becomes nitrified to the same extent as that from the fertilizer containing dolomitic limestone, the difference in the pH values of the soils treated with the two fertilizers will naturally become greater. It must be emphasized also that the low pH values after 122 days as compared with those at the beginning of the experiment even where the dolomitic limestone had been used are due to the high salt concentration allowed to develop under the conditions of the experiment and to the fact that the equivalent acidity values given for the fertilizer are based on the presence of plant growth. These factors are discussed further on pages 637 to 640.

The data obtained with the more acid Dekalb silt loam soil are shown in Fig. 6. As with the other soil, there is found a close relationship between the pH changes and the rate of nitrification. With the 0–8–6 fertilizer, and also with the 6–8–6 fertilizer not containing dolomitic limestone, little nitrification took place, and as will be seen in Fig. 6, there was little change in pH from the 45th to the 134th day. The higher pH obtained with the acid-forming 6–8–6 fertilizer can be explained again by the formation of ammonium carbonate from urea and the fact that nitrification of the ammonium carbonate did not take place on account of the high salt concentration and the high acidity. With the 6–8–6 fertilizer containing dolomitic limestone there was found to be a rapid rise in pH at the time of the first sampling, and a steady decrease thereafter as nitrification proceeded rapidly.

Concentration of soluble magnesium in the soil-fertilizer zone.—The soluble magnesium contents of the soil for the various intervals after fertilization are shown in Figs. 7, 8, and 9. The data are given as p.p.m. on the dry-soil basis. It is apparent from the data that all

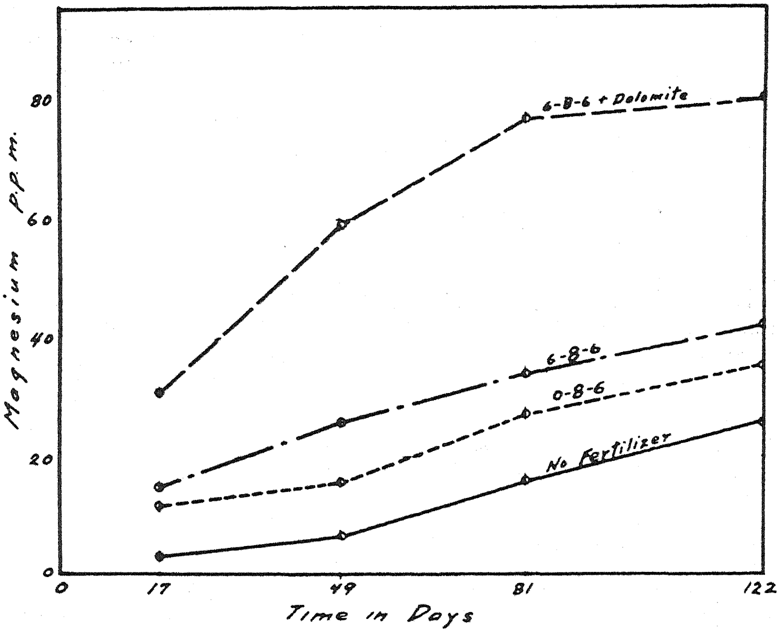

FIG. 7.—Soluble magnesium in fertilizer zone after various intervals; soil 745, Dekalb loam; low rate of fertilization.

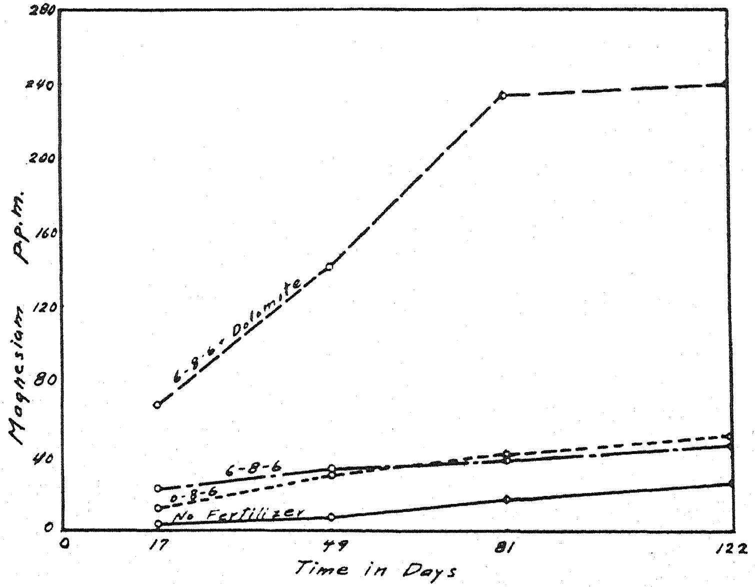

FIG. 8.—Soluble magnesium in fertilizer zone after various intervals; soil 745, Dekalb loam; high rate of fertilization.

fertilizers, even those to which no magnesium compounds were added, increased the water-soluble magnesium content of the soil. This is explained by the fact that the addition of soluble salts, such as potassium chloride and calcium sulfate, results in a liberation of bases from the exchange complex and thus tends to bring some magnesium into solution. The comparison of primary interest, however, is between the effects of the acid-forming fertilizer and the potentially neutral fertilizers containing dolomitic limestone. With the low rate of fertilization it will be noted from Fig. 7 that the concentration of water-soluble magnesium in the soil is about twice as high with the potentially neutral fertilizer as with the acid-forming fertilizer of similar analysis. The data in Fig. 8 show that with the high rate of fertilization on the same soil the dolomitic limestone in the fertilizer caused a three- to fivefold increase in the soluble magnesium content of the soil. Similar increases are shown in Fig. 9 for the Dekalb silt loam soil.

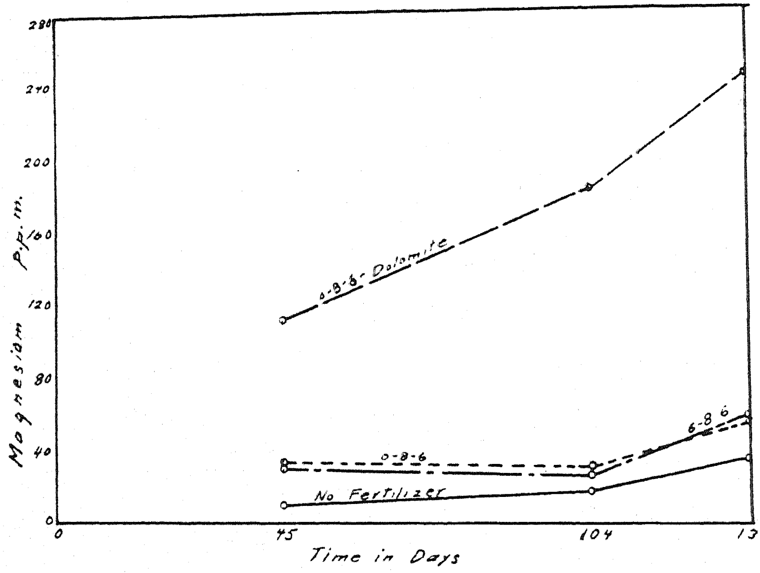

FIG. 9.—Soluble magnesium in fertilizer zone after various intervals; soil 744, Dekalb silt loam; high rate of fertilization.

The concentration of magnesium in the soil-fertilizer zone will be affected, of course, by the fineness of the dolomitic limestone. Data on this point for limestones of different degrees of fineness will be presented in a later paper (9).

EXPERIMENT II. CHANGES IN THE SOIL-FERTILIZER ZONE AND PLANT GROWTH RESPONSES FROM THE USE OF NEUTRAL FERTILIZERS

EXPERIMENTAL PROCEDURE

Nine soils obtained from West Virginia, South Carolina, and Alabama, and varying in pH from 4.60 to 5.40 and in texture from a loamy sand to silt loam, were used in this study. Each soil was mixed thoroughly and definite amounts, varying among the different soils from 7,500 to 1,100 grams, were placed in 2-gallon glazed earthenware pots. Half of these pots in each series were fertilized with an acid-forming fertilizer and the remainder with a similar fertilizer, except that it contained dolomitic limestone to make it non-acid-forming. The analysis of the fertilizers and their equivalent acidity values are given in Table 2. Seventy-five per cent of the nitrogen in the 6–8–6 fertilizer came from ammonium sulfate, 16.67% from sodium nitrate, and 8.33% from Ammo-phos; whereas in the 4–6–6 fertilizer 62.5% came from ammonium sulfate, 25% from sodium nitrate, and 12.5% from ammonium phosphate. In the 4–10–6 fertilizer, 75% of the nitrogen came from ammonium sulfate and 25% from ammonium phosphate. In all the above fertilizers, part of the phosphate came from ammonium phosphate and the remainder from superphosphate, and all the potassium came from muriate of potash.

Sand was used as a filler in the acid-forming and dolomitic limestone in the potentially neutral fertilizer. The limestone used in the neutral fertilizer analyzed 56.08% calcium carbonate and 43.64% magnesium carbonate. The mechanical analysis was as follows: All went through a 40-mesh sieve; 20% was held on the 60-mesh, 20% on the 80-mesh, 10% on the 100-mesh, and 50% was finer than 100-mesh.

The fertilizer in each case was mixed with one-tenth of the total amount of soil in the pot and placed in the form of a cylindrical column in the middle of the pot by means of a metal cylinder open at both ends. The untreated soil then was placed around the metal cylinder and packed lightly. A circular metal collar, painted with asphaltum paint, 1½ inches in height and slightly larger than the cylinder, was placed over the end of the cylinder and imbedded about ½ inch in the soil, and the metal cylinder then was removed. Sudan grass was planted in the unfertilized soil in a circular arrangement about 1 inch from the collar. Distilled water was added as needed to bring the soil up to approximately optimum moisture conditions. All treatments were either in duplicate or triplicate.

Soil samples were removed from within the soil-fertilizer zone 3 weeks after fertilization and determinations made on the water extract for pH, nitrates, magnesium, calcium, and phosphate. The remainder of each soil sample taken at this time was kept in a beaker at approximately optimum moisture conditions for another 3 weeks, after which the concentration of water-soluble phosphate again was determined. At the time of harvesting, soil samples were taken from the soil-fertilizer zone and also from the unfertilized soil and pH determinations made. Phosphates were determined by the colorimetric method as described by Parker and Fudge (5), calcium by the standard method, and the other determinations by the methods used in Experiment I.

EXPERIMENTAL RESULTS

Nitrates and pH in the soil-fertilizer zone.—In Table 2 data are presented showing the effect of acid-forming and potentially neutral fertilizers containing dolomitic limestone on nitrate accumulation 3 weeks after fertilization and on the pH values of the nine soils after 3 weeks and at harvest time. It is seen that even after only 3 weeks all the soils studied showed a higher nitrate accumulation with the neutral than with the acid-forming fertilizer, although in some cases the increase was very small. If soil 755, for which no nitrate data are

TABLE 2.—*The effect of acid-forming and of neutral fertilizers on the nitrate concentration and the pH of the soil in the fertilizer zone.*

Soil No.	Soil type	Fertilizer treatment*	Nitrate-nitrogen, p.p.m.			pH of soil					
			After 3 weeks			At beginning of experiment	After 3 weeks		At harvest		Outside soil-fertilizer zone at harvest
			At beginning	Acid-forming fertilizer	Neutral fertilizer		Acid-forming fertilizer	Neutral fertilizer	Acid-forming fertilizer	Neutral fertilizer	
746	Dekalb silt loam	10,000 lbs. 4–8–6	11.2	61.1	91.2	5.40	5.20	5.70	4.85	5.33	5.33
747	Dekalb silt loam	10,000 lbs. 4–8–6	19.8	62.0	64.8	4.75	4.70	5.20	4.53	4.93	4.70
748	Dekalb fine sandy loam	10,000 lbs. 4–8–6	0	20.5	39.3	4.73	4.80	5.30	4.83	4.85	4.50
749	Wheeling fine sandy loam	10,000 lbs. 4–8–6	23.6	63.8	89.6	5.05	4.95	5.55	4.68	5.03	4.95
751	Norfolk loamy sand (S. C.)	8,000 lbs. 4–6–6	0	46.9	51.8	5.10	5.00	5.60	N.D.	N.D.	N.D.
753	Monongahela fine sandy loam	8,000 lbs. 4–10–6	0	30.4	43.5	4.95	4.75	5.03	4.73	4.88	4.80
754	Pope loam	8,000 lbs. 4–10–6	0	18.8	30.5	5.40	4.98	5.10	4.68	4.92	5.13
755	Holston silt loam	8,000 lbs. 4–10–6	N.D.†	34.4	40.0	4.80	4.53	4.83	4.48	4.68	4.68
756	Norfolk sandy loam (Ala.)	8,000 lbs. 4–10–6	0	9.7	16.8	5.40	5.00	5.30	4.85	5.07	5.10

*Equivalent acidity values for acid-forming fertilizers:
6–8–6 = 500 lbs. per ton
4–6–6 = 285 lbs. per ton
4–10–6 = 428 lbs. per ton
Rate of fertilization given is on the basis of the fertilized zone and is expressed as pounds per 2,000,000 pounds of soil.

†N.D. = Not determined.

available at the beginning of the experiment, is excluded, it is found that approximately 44% more ammonia was nitrified with a neutral than with an acid-forming fertilizer.

As might be expected, the use of a potentially neutral fertilizer as compared with an acid-forming one increased the pH of the soil in the fertilizer zone in all cases after 3 weeks' time and on all but one soil (No. 748) at harvest. In the latter soil the acid-forming fertilizer did not cause an increase in acidity. This no doubt can be explained by two facts; first, nitrification of the added ammonia was very slow as a result of the combination of high acidity and high salt concentration; and second, plants made practically no growth where the acid-forming fertilizer was used. As the ammonia supplied by the fertilizer gradually nitrifies, the pH value no doubt will be decreased. On the other hand, considerable nitrification and plant growth resulted where the potentially neutral fertilizer was used. The low pH value of the soil on the outside of the fertilizer zone at harvest probably is due to nitrification of the soil organic matter, for it has been found in other experiments with this soil that considerable nitrification takes place in the absence of a high salt concentration. It is interesting to note the similarity in pH of the soil inside the soil-fertilizer zone at harvest where a potentially neutral fertilizer was used and the pH of the unfertilized soil. Of the eight soils reported, five show approximately the same pH values, while three show some differences.

Concentration of phosphate, magnesium, and calcium in the soil-fertilizer zone.—The effect of acid-forming and potentially neutral fertilizers containing dolomitic limestone on the concentration of water-soluble phosphate in the soil-fertilizer zone 3 and 6 weeks after fertilization is given in Table 3. It is interesting to note in comparing the results obtained with a neutral and an acid-forming fertilizer that the use of the former caused an increase in concentration of phosphate in the soil-fertilizer zone on four of the nine soils studied. Although in some cases the differences were small, it is observed that they still persisted even 6 weeks after fertilization. This shows that with soils that are very acid or those that have a high fixing power for phosphorus, the use of a potentially neutral instead of an acid-forming fertilizer may increase the concentration of water-soluble phosphate in the soil-fertilizer zone.

The concentration of soluble magnesium in the soil-fertilizer zone 3 weeks after fertilization is also given in Table 3. The results show, as was brought out in Experiment I, that the addition of dolomitic limestone to make the fertilizer non-acid-forming caused a considerable increase in concentration of water-soluble magnesium in the soil-fertilizer zone. Even after only 3 weeks' time, on two of the soils studied (Nos. 746 and 748), the concentration of soluble magnesium was more than trebled as a result of using a potentially neutral fertilizer containing dolomitic limestone. It is interesting to compare the concentration of soluble magnesium in the soil-fertilizer zone on the loamy sand No. 751 where a neutral and where an acid-forming fertilizer was used. As can be seen, the use of the former more than doubled the concentration of magnesium even though the acid-

TABLE 3.—*The effect of acid-forming and neutral fertilizers on the water soluble PO_4, magnesium, and calcium in the soil of the fertilized zone after various intervals of time.*

Soil No.	Soil type	pH of untreated soil	Fertilizer treatment*	Water-soluble PO_4, p.p.m.				Water-soluble Mg, p.p.m.		Water-soluble Ca, p.p.m.	
				After 3 weeks		After 6 weeks		After 3 weeks		At harvest	
				With acid-forming fertilizer	With neutral fertilizer	With acid-forming fertilizer	With neutral fertilizer	With acid-forming fertilizer	With neutral fertilizer	With acid-forming fertilizer	With neutral fertilizer
746	Dekalb silt loam	5.40	10,000 lbs. 6–8–6	5.50	7.00	3.35	4.25	21.9	70.8	547	795
747	Dekalb silt loam	4.75	10,000 lbs. 6–8–6	4.63	5.13	2.65	3.25	39.4	71.7	413	811
748	Dekalb fine sandy loam	4.73	10,000 lbs. 6–8–6	1.76	1.94	0.82	1.22	26.4	90.3	327	724
749	Wheeling fine sandy loam	5.05	10,000 lbs. 6–8–6	7.50	7.50	5.60	5.90	53.4	108.5	723	804
751	Norfolk loamy sand (S. C.)	5.10	8,000 lbs. 4–6–6	20.35	25.65	15.15	19.70	18.6	43.7	N.D.	N.D.†
753	Monongahela fine sandy loam	4.95	8,000 lbs. 4–10–6	9.53	9.38	6.00	6.25	41.0	67.2	126	373
754	Pope loam	5.40	8,000 lbs. 4–10–6	11.75	10.90	6.38	6.63	52.3	75.2	385	449
755	Holston silt loam	4.80	8,000 lbs. 4–10–6	3.38	3.81	2.50	2.69	63.9	79.3	178	305
756	Norfolk sandy loam (Ala.)	5.40	8,000 lbs. 4–10–6	20.60	20.70	15.80	15.70	29.0	46.3	138	158

*Equivalent acidity values for acid-forming fertilizers:
6–8–6 = 500 lbs. per ton
4–6–6 = 285 lbs. per ton
4–10–6 = 428 lbs. per ton
Rate of fertilization given is on the basis of the fertilized zone and is expressed as pounds per 2,000,000 pounds soil.
†N.D. = Not determined.

forming fertilizer had an equivalent acidity of only 285 pounds calcium carbonate per ton.

In the last two columns of Table 3 are given the concentration of water-soluble calcium in the soil after harvesting the crop. In all cases the calcium is much higher with the neutral than with the acid-forming fertilizer. Determinations of calcium were also made on soil samples removed 3 weeks after fertilization. The concentrations present at this time were very high and showed little differences with the two types of fertilizers. This is what might be expected since large amounts of calcium sulfate were applied in the fertilizer.

Plant growth and yield data.—The yields of Sudan grass in grams of dry weight per pot are given in Table 4. Results obtained from eight different soils show that the potentially neutral fertilizers produced higher yields than did the acid-forming fertilizer on four of the soils and had little effect on the others. These increases in yield were obtained, with one exception, on the four most acid soils and the greatest increase was obtained on the most acid soil (No. 748). It should be mentioned that during the early stages of growth, some of the other soils produced poorer growth where the acid-forming fertilizers were used, but in these cases the injurious effect of acidity was overcome largely, before harvest. This was especially true on soils 747 and 756. The yield from one pot of soil 754, where an acid-forming fertilizer was used, is considerably higher than its companion pots, but no explanation is available for this behavior. In Fig. 10 is shown the effect of an acid-forming and potentially neutral fertilizer containing dolomitic limestone on the growth of Sudan grass in the greenhouse for 39 days on soils 753 and 755.

GENERAL DISCUSSION

While, as emphasized previously, the main value of neutral fertilizers in general is the prevention of a harmful increase in soil acidity over a period of years, their advantage over acid-forming fertilizers may become evident during the first year if the soil already is very acid, or if deficient in available magnesium. In the greenhouse experiments reported in this paper the beneficial effect of neutral over acid-forming fertilizers probably was due to differences in acidity found in the soil-fertilizer zone. These differences need not be large, of course, if the pH value of the soil is near the critical point for the plant being grown.

The pH values obtained in experiment I are of interest primarily in illustrating the close correlation existing between nitrification and the development of acidity in uncropped soils. Where nitrification of the ammonia of the acid-forming fertilizer was inhibited because of the high soil acidity already existing and to the high salt concentration, there was, as would be expected, little, if any, increase in acidity. The true effect of the acid-forming fertilizer on soil acidity, therefore, was not developed during the duration of the experiment. Moreover, this experiment illustrates the effect of salt concentration on the pH of soils. Thus, the pH values obtained with the potentially neutral fertilizers were considerably lower than those of the original soils. It should be recognized, however, that this effect is not permanent but is due to a slight exchange of the cation of the neutral salts (calcium sulfate, potassium chloride, etc.) with the hydrogen in the soil-exchange complex. Where plants were growing on the soils as in experiment II and where there was some opportunity for the salts to diffuse from the heavily fertilized soil zone, the potentially neutral fertilizer maintained the soil at about the original pH value.

TABLE 4.—*The effect of acid-forming and neutral fertilizers on the yield of Sudan grass in greenhouse experiments.*

Soil No.	Soil type	pH of untreated soil	Fertilizer treatment*	Yield of Sudan grass, grams dry weight per pot			
				With acid-forming fertilizer		With neutral fertilizer	
				Individual	Average	Individual	Average
746	Dekalb silt loam	5.40	10,000 lbs. 6-8-6	33.3 38.8	36.1	32.6 36.5	34.6
747	Dekalb silt loam	4.75	10,000 lbs. 6-8-6	35.7 34.6	35.2	36.0 38.0	37.0
748	Dekalb fine sandy loam	4.73	10,000 lbs. 6-8-6	0.5 0.7	0.6	12.3 8.4	10.4
749	Wheeling fine sandy loam	5.05	10,000 lbs. 6-8-6	29.2 31.7	30.5	36.7 34.0	35.4
751	Norfolk loamy sand (S. C.)	5.10	8,000 lbs. 4-6-6	—†	—	—	—
753	Monongahela fine sandy loam	4.95	8,000 lbs. 4-10-6	15.5 17.7 14.7	16.0	25.1 26.9 25.5	25.8
754	Pope loam	5.40	8,000 lbs. 4-10-6	23.2 34.0 24.9	27.4	27.3 28.6 27.6	27.7
755	Holston silt loam	4.80	8,000 lbs. 4-10-6	16.9 21.7 18.7	19.1	23.7 25.2 27.4	25.4
756	Norfolk sandy loam (Ala.)	5.40	8,000 lbs. 4-10-6	16.6 16.2 14.3	15.7	15.9 17.4 19.8	17.7

*Equivalent acidity values for acid-forming fertilizers:
6-8-6 = 500 lbs. per ton
4-6-6 = 285 lbs. per ton
4-10-6 = 428 lbs. per ton
Rate is on basis of fertilizer zone. If it is assumed that the fertilizer zone represents 1/10 to 1/20 of the acre 6⅔ inches, the actual rates per acre would be 1/10 to 1/20 these amounts.

†Sudan grass was not grown on this soil.

It should be emphasized also that the acidity developed by ammonium fertilizers in uncropped soils is higher than where crops are growing. Thus, it has been shown that where plants are growing one-half of the nitrogen applied in fertilizers, in general, can be considered

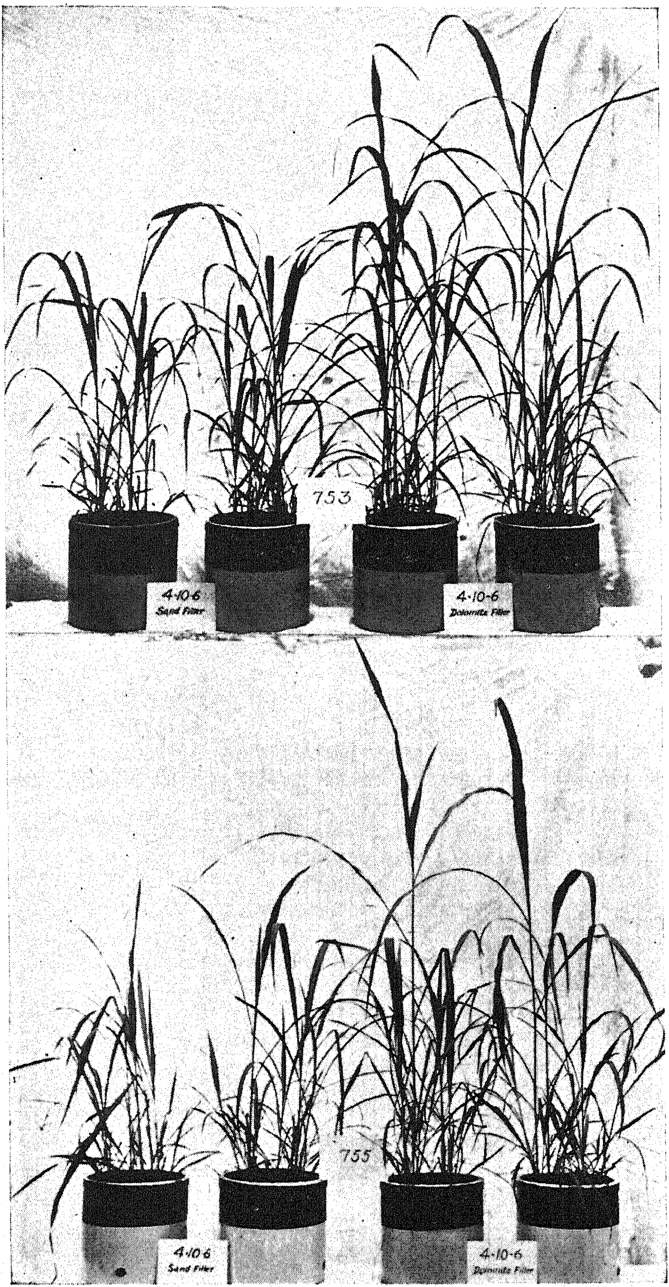

FIG. 10.—Growth of Sudan grass on Monongahela fine sandy loam (No. 753) and Holston silt loam (No. 755) with an acid-forming (left) and a neutral (right) fertilizer.

acid-forming (6, 7). Where plants are not growing, however, and where complete nitrification takes place, the nitrogen should exert its full acid effect on the soil. The non-acid-forming fertilizers used in experiment I, therefore, would not be expected to maintain the pH at its original value even if salt concentration had not been a factor.

The foregoing discussion emphasizes some of the factors that must be considered in evaluating the permanent effect of fertilizers on soil acidity. Not only may non-acid-forming fertilizers cause a temporary increase in acidity as a result of high salt concentration or of other factors, but it also has been shown in this investigation that acid-forming fertilizers may temporarily decrease the acidity of the soil in the heavily fertilized soil zone. Thus, the use of urea in a mixed fertilizer caused a temporary increase in the pH of the soil fertilizer zone. These temporary effects of fertilizers on soil acidity may be important under certain conditions, but they should be distinguished clearly from the permanent effects, which are considered the criteria of whether or not a fertilizer is acid-forming.

SUMMARY

In this investigation studies were made on soils in the laboratory and in the greenhouse regarding the comparative effects of acid-forming and potentially neutral fertilizers containing dolomitic limestone supplements on plant growth and on the following chemical and biological changes in the soil-fertilizer zone: (a) Nitrification of added ammonia, (b) pH values, and (c) concentration of water-soluble magnesium, calcium, and phosphate. Eleven different soils obtained from West Virginia, South Carolina, and Alabama and varying in pH from 4.73 to 5.40 were used in the study.

The results show that on the relatively acid soils studied potentially neutral fertilizers containing dolomitic limestone supplements promoted nitrification in the soil-fertilizer zone to a much greater extent than did acid-forming fertilizers. This was true especially on the more acid soils and where the rate of fertilization was high. Thus, in some cases, 4 to 15 times as high a percentage of the added ammonia was nitrified where the potentially neutral fertilizer was used.

The pH of the soil in the fertilizer zone is substantially higher where potentially neutral than where acid-forming fertilizers are used. This is true particularly where the high rate of fertilization was used and during the first few weeks after fertilization. Thereafter, as the differences between the amount of nitrates produced with the two types of fertilizers increased, the pH differences decreased.

Urea in a complete fertilizer tended to cause a temporary increase in the pH of the soil in the fertilizer zone, apparently as the result of the formation of ammonium carbonate. With the high rate of fertilizer application and on a very acid soil, a small increase in pH was found to persist for several months. This is explained by the fact that under these conditions nitrification of the ammonium carbonate was slow.

Mixed fertilizers containing dolomitic limestone to make them non-acid-forming caused a marked increase in the concentration of water-soluble magnesium in the soil-fertilizer zone. With a low rate of fertilization the concentration of magnesium in the medium-acid Dekalb loam was more than doubled by the use of dolomitic limestone in the fertilizer mixture. Where a high rate of fertilization was used, the increase was three to five times as great. Similar increases were obtained with other soils.

The use of a potentially neutral rather than an acid-forming fertilizer caused a definite increase in concentration of water-soluble phosphate in the soil-fertilizer zone after 3 and 6 weeks' time on four of the nine soils studied. The remaining soils gave no significant differences in concentration of soluble phosphate.

Yields of Sudan grass from eight different soils show that a potentially neutral fertilizer produced a higher yield than did the acid-forming fertilizer on four of the soils and had little effect on the others. In general, the greatest differences in yields obtained with the two types of fertilizers were on the most acid soils.

It is emphasized that the temporary effect of fertilizers on soil acidity should be distinguished clearly from their permanent effects.

LITERATURE CITED

1. Clark, H. E., and Shive, J. W. The influence of the pH of a culture solution on the rates of absorption of ammonia and nitrate nitrogen by the tomato plant. Soil Science, 37: 203–225; 459–476. 1934.
2. Davidson, O. W., and Shive, J. W. The influence of the hydrogen-ion concentration of the culture solution upon the absorption and assimilation of nitrate and ammonia nitrogen by peach trees grown in sand cultures. Soil Science, 37: 357–385. 1934.
3. Kramer, B., and Tisdall, F. F. A simple technique for the determination of calcium and magnesium in small amounts of serum. Jour. Bio. Chem., 47: 475. 1921.
4. Naftel, James A. The absorption of ammonium and nitrate nitrogen by various plants at different stages of growth. Jour. Amer. Soc. Agron., 23: 142–158. 1931.
5. Parker, F. W., and Fudge, J. F. Soil phosphorus studies: I. The colorimetric determination of organic and inorganic phosphorus in soil extracts and in soil solution. Soil Science, 24: 109–118. 1927.
6. Pierre, W. H. Determination of equivalent acidity and basicity of fertilizers. Ind. and Eng. Chem., Anal. Ed., 5: 229–234. 1933.
7. ————. Nitrogenous fertilizers and soil acidity: I. Effect of various nitrogenous fertilizers on soil reaction. Jour. Amer. Soc. Agron., 20: 254–269. 1928.
8. ————, and Parker, F. W. The use of collodion sacks in obtaining clear soil extracts for the determination of water-soluble constituents. Soil Science, 23: 13–32. 1927.
9. Taylor, J. R., Jr., and Pierre, W. H. Non-acid forming mixed fertilizers: II. The value of dolomitic limestone supplements of different degrees of fineness as measured by the increase in water-soluble magnesium in the soil. Jour. Amer. Soc. Agron. (In press.)
10. Tiedjens, V. A. Factors affecting assimilation of ammonium and nitrate nitrogen, particularly in tomato and apple. Plant Phys., 9: 31–57. 1934.
11. ————, and Robbins, W. R. The use of ammonia and nitrate nitrogen by certain crop plants. N. J. Agr. Exp. Sta. Bul. 526. 1931.

VITALITY AND GERMINATION OF CRIMSON CLOVER SEED AS AFFECTED BY SWELLING AND SPROUTING AND SUBSEQUENT DRYING[1]

ROLAND McKEE[2]

ALTHOUGH germination of seed and subsequent survival are influenced by weather and seedbed conditions, the relative difference in ease or assurance with which a crop makes a stand can not be attributed to these factors alone. The characteristics which make crops inherently different are influencing factors and must be given consideration in any study of the subject.

In vernalization experiments with crimson-clover (unpublished), it has been noted that in cases where the seed has germinated sufficiently to have the radicle protruding and the seed subsequently dried, poor stands and growth result. In order to determine more definitely the effect of swelling and sprouting and subsequent drying on the vitality and germination, the experiments herein reported were undertaken. These were carried out in an ordinary laboratory room at a temperature of 20° to 22°C.

Hulled crimson clover seed was germinated for varying intervals and then dried at ordinary room temperature. After drying for from 8 to 10 days the seed was again started into growth, as indicated in the tabulated data (Table 1). The seed moistened for 22 hours fully swelled but showed no radicle elongating. The radicles began to appear in 27 hours, however, and were 10 mm long in 76 hours. It will be noted from the tabulation that seed that had the radicle showing when dried was seriously injured, while seed in which the radicle had not yet appeared was hurt but little. Longer periods of drying than indicated in the table gave similar results. When the time of drying slightly sprouted seed was varied from 52 to 192 hours, the drying in all cases injured the seed, the amount of injury increasing with the length of time.

TABLE 1.—*Laboratory test with crimson clover seed.*

Treatment No.	Preliminary treatment Jan. 22 to Jan. 30			Laboratory germination test in blotters Jan. 30 to Feb. 8		
	No. hours in contact with H_2O	Length of radicle in mm	No. hours dried after moistening	Per cent cotyledons greening	Per cent good plants	Vigor and height of plants
1	22	0	169	90	85	Strong, 4 cm
2	27	1	164	90	45	Medium, 2 cm
3	45	5	146	25	5	Weak, 1 cm
4	69	10	122	15	5	Weak, 1 cm
5	76	10	115	15	0	None

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[1] Contribution from the Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture. Received for publication May 10, 1935.

[2] Senior Agronomist.

To determine further the effect of continuing the swelled period for various lengths of time without the radicle appearing, one lot of seed was moistened for 1 hour and then dried, while another was kept moist 42 hours before drying. These were compared with a check lot of seed that had not been moistened.

The lot that had been in contact with moisture 42 hours, upon remoistening, germinated first and was appreciably ahead of the 1-hour lot. The check was slowest in starting and was appreciably behind the 1-hour lot. The percentage of germination of the various lots was 77 for the 42-hour lot, 73 for the 1-hour lot, and 71 for the check. In other tests with this same general lot of seed, the checks have germinated as much as 80% with the average being about 75%. From this test, it is indicated that swelling and subsequent drying for several days, if the radicle has not appeared, does not affect the vitality of the seed, and that when it is remoistened, growth starts quicker than in untreated seed.

In connection with studies (unpublished) on arrested growth in the germinating or seedling stage of certain other crops, it has been observed that the ability of seedlings to recover after once started into active growth and subsequently dried, varies widely. Many grasses recover readily after being sprouted with the radicle and plumule both well started into growth and subsequently thoroughly air-dried. The same is true of some legumes with hypogeous cotyledons, but apparently not true or only partially so with legumes with epigeous cotyledons.

These data and observations help to explain why crimson clover is an undependable crop in obtaining stands, as indicated by the general experience of farmers.

THE RELATION BETWEEN EFFECTIVE RAINFALL AND TOTAL CALCIUM AND PHOSPHORUS IN ALFALFA AND PRAIRIE HAY[1]

Harley A. Daniel and Horace J. Harper[2]

ALTHOUGH a considerable amount of research has been conducted on the mineral content of forage, only a few correlations have been made between the effective seasonal rainfall and the total calcium and phosphorus in plants. Orr (14)[3] reported data on oat hay which was low in calcium and high in phosphorus during a wet season. Ferguson (9), and Woodman, Norman, and French (19) found that a prolonged drouth caused a decrease in the percentages of nitrogen and phosphorus and an increase in the calcium content of pasture plants. McCreay (13), Archibald, Nelson, and Bennett (2), and Eckles, Becker, Berton, and Palmer (7) found that the phosphorus content of forage plants varied directly with rainfall.

The effect of maturity on the mineral content of plants has been studied by several investigators (1, 3, 4, 5, 8, 10, 16). Results have been secured which show that the total phosphorus and nitrogen are highest in young plants and decrease as the plants mature; whereas, the percentage of total calcium increases during the earlier stages of plant development, reaching a maximum in early summer, and then decreases slowly as growth continues. Other factors which may affect the mineral content of plants are soil conditions (11, 12), kind of plant (6), and fertilizer application (15, 17, 18).

Due to the wide variation in climatic conditions which occur in Oklahoma and to the intermittent occurrence of evidence indicating that mineral deficiencies frequently appear in different types of livestock, a series of experiments have been conducted to determine the effect of rainfall and fertilization on the mineral content of native grass and alfalfa hay.

EXPERIMENTAL PROCEDURE

In 1929 an experiment was started at the Oklahoma Agricultural Experiment Station to study the effect of the addition of nitrogen, phosphorus, and potassium fertilizers on the growth and composition of native grass. An area of uniform soil which was covered with vegetation composed chiefly of little blue stem (*Andropogon scoparius*) was divided into 30 plats and the different fertilizer treatments were broadcasted annually on the surface of the soil about the first of April. Every third plat received no treatment in order to study differences in soil variation and the effect of different fertilizers on growth and yield. Composite samples of grass were obtained for analysis at the time the hay was harvested. The samples were collected each year from 1929 to 1933.

The soil on which this experiment was located is Kirkland loam. The surface soil is brown in color, and is underlaid by a dark red compact clay subsoil. It is

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[1] Contribution from the Department of Agronomy, Oklahoma Agricultural Experiment Station, Stillwater, Okla. Received for publication May 13, 1935.

[2] Assistant Agronomist and Professor of Soils, respectively.

[3] Figures in parenthesis refer to "Literature Cited," p. 651.

slightly acid, but the acidity decreases with depth, a neutral reaction usually being encountered at 12 to 18 inches below the surface.

Another experiment was started in 1931 on the Perkins farm of the Oklahoma Agricultural Experiment Station to study the effect of different phosphate fertilizers, complete fertilizers prepared from high and low analysis material, and farm manure used alone and supplemented with phosphorus and potassium on the growth and composition of alfalfa hay. All fertilizers were cultivated into the seedbed in the spring of 1931 before the alfalfa was planted. In 1932 and 1933 the fertilizers which were to be applied annually were broadcasted on the surface of the soil about March 15. No crop was harvested the first season. Three cuttings of alfalfa hay were obtained in 1932 and in 1933. At each cutting, samples of hay were secured from 68 plats. Since each fertilizer treatment was repeated four times in this experiment, all samples from plats receiving the same treatment were combined into one composite sample for analysis, making a total of 17 samples for analyses.

The soil on which this experiment was located is a brown sandy loam and is very similar to the Bates series. The surface soil is underlaid by a friable sandy clay which does not restrict the movement of soil moisture or root development.

All of the native grass and alfalfa hay was dried at 105° C, and analyzed for total calcium and phosphorus by official methods recommended by the Association of Official Agricultural Chemists.

RELATION BETWEEN TOTAL ANNUAL, TOTAL SEASONAL, EFFECTIVE ANNUAL, AND EFFECTIVE SEASONAL RAINFALL

An exact comparison of the variation in quantity of plant food in forage as affected by rainfall is not easy to make since some rains are small and scarcely moisten the surface of the soil, while other rains may be large and a portion may be lost either as gravitational water or by runoff when torrential rainfall occurs. Under the climatic conditions which prevail in this area much of the moisture which falls during the winter when plants are dormant may be lost by evaporation since a low humidity occurs during a considerable portion of this period.

In order to study the relation between rainfall and the calcium and phosphorus content of prairie grass and alfalfa, some consideration must be given to the nature of the rains occurring during the period of plant development. In order to obtain data on the relative differences between annual and seasonal rainfall, results secured at Stillwater, Okla., for the 5-year period from 1929 to 1933, inclusive, are shown in Fig. 1. Rains of less than 0.5 inch were classified as ineffective since the major portion of such showers are lost by evaporation. Total rainfall in excess of 2 inches for each rain was also classified as ineffective, since a large portion of torrential rainfall is lost by runoff.

Although the different rainfall curves are quite similar in character, a greater variation occurred in 1931 and 1932 as compared with data obtained during the other 3 years. Since only that moisture which penetrates into the soil and stays in the zone of root development will have any appreciable influence on plant growth, effective rainfall should correlate more closely with variations in plant composition and development than total rainfall. Whether total effective rainfall should be selected as a basis for comparison instead of effective seasonal rainfall, may be determined from a study of factors which contribute to moisture losses from the soil. Lysimeter studies at the Oklahoma Agricultural Experiment Station indicate that loss of water by percolation is negligible, due to the small amount of rainfall which occurs during the winter months; consequently, curves for effective seasonal rainfall and effective total rainfall should be similar in character. Effective rainfall which occurs

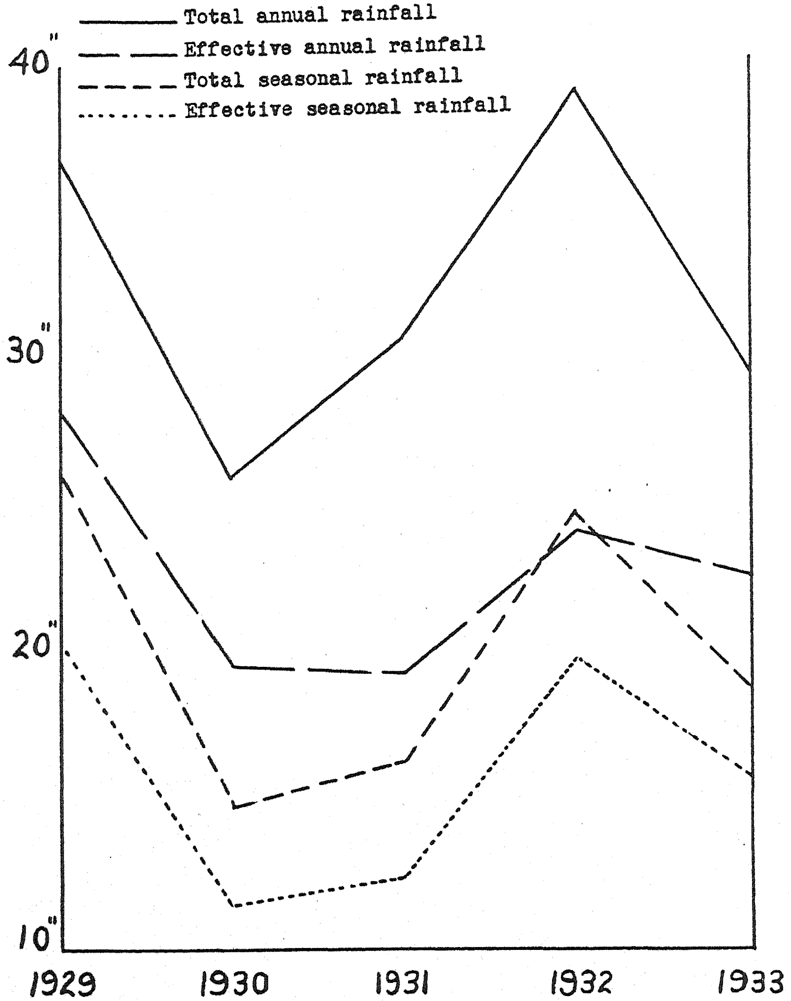

FIG. 1.—The relation between total annual, effective annual, total seasonal, and effective seasonal rainfall at Stillwater, Okla., from 1929 to 1933, inclusive.

in late fall tends to disappear from the soil by evaporation and, although some of it may penetrate into the subsoil, it produces very little effect on the growth of native grass or alfalfa the following season unless supplemented by additional moisture derived from spring rains. As a result of these observations, comparisons have been made between effective seasonal rainfall and the calcium and phosphorus content of crops.

COMPARISON BETWEEN EFFECTIVE SEASONAL RAINFALL AND TOTAL CALCIUM AND PHOSPHORUS IN NATIVE PRAIRIE HAY AND ALFALFA

In order to study the relation between the effective seasonal rainfall and the mineral content of plants, rain that fell between January 1 and the time the prairie hay was harvested was compared with the total calcium and phosphorus in each crop. Since alfalfa produces more than one crop of hay each year, the calcium and phosphorus in the first cutting of alfalfa was compared with the effective rainfall which occurred between January 1 and the date on which the first crop of hay was harvested. Effective rains which fell between the different cutting dates were compared with the composition of forage produced during a similar period. Such a comparison introduces some error since a heavy rain may occur a few days before a crop is harvested and that moisture would be used by the following crop. It is quite possible that a better correlation between plant composition and rainfall would be obtained if more accurate information were obtained on the influence of the available moisture in the soil on plant composition. This phase of the problem is being studied under greenhouse conditions where soil moisture conditions can be carefully regulated.

The relationship between the effective seasonal rainfall and total calcium and phosphorus content of the unfertilized native prairie hay are given in Table 1. These data show that a considerable variation in total calcium and phosphorus occur between samples of forage produced on different plats which were treated in a similar manner; however, these variations are usually small when compared with seasonal fluctuations. Although fertilizer treatment slightly increased the phosphorus content of mature prairie hay, this variation was insignificant as compared with differences which occurred in the composition of forage produced during different seasons. The average total phosphorus content of prairie hay varied from 0.07% in 1930 to 0.138% in 1932. The average calcium content varied from 0.311% in 1929 to 0.610% in 1931.

The effective seasonal rainfall was high during the seasons of 1929 and 1932 and the average percentage of total calcium in the mature native grass was only 0.311 and 0.315% for 1929 and 1932, respectively. In 1930 and 1931, the effective seasonal rainfall was low and the prairie hay was very high in calcium, containing 0.475 and 0.610% for each year, respectively.

Data on the effective seasonal rainfall and the calcium and phosphorus content of the different cuttings of alfalfa are given in Table 2. The first crop of alfalfa in 1932 contained an average of 2.18%

TABLE 1.—*Data on the total calcium and phosphorus in unfertilized prairie hay and effective seasonal rainfall.**

Sample No.	1929		1930		1931		1932		1933	
	Ca Per cent	P Per cent	Ca Per cent	P Per cent	Ca Per cent	P Per cent	Ca Per cent	P Per cent	Ca Per cent	P Per cent
1	0.419	0.098	0.367	0.064	0.480	0.079	0.399	0.098	0.318	0.086
2	0.301	0.094	0.476	0.066	0.745	0.095	0.418	0.090	0.453	0.133
3	0.288	0.069	0.485	0.064	0.650	0.070	0.362	0.176	0.365	0.144
4	0.288	0.083	0.596	0.088	0.715	0.090	0.340	0.105	0.365	0.081
5	0.314	0.083	0.342	0.082	0.560	0.093	0.312	0.141	0.398	0.134
6	0.262	0.096	0.485	0.066	0.577	0.092	0.272	0.119	0.435	0.113
7	0.270	0.079	0.668	0.066	0.731	0.080	0.286	0.185	0.360	0.150
8	0.275	0.069	0.432	0.096	0.585	0.082	0.274	0.121	0.313	0.097
9	0.367	0.095	0.452	0.069	0.535	0.089	0.272	0.148	—	—
10	0.328	0.079	0.445	0.067	0.520	0.089	0.235	0.095	0.428	0.085
Average	0.311	0.084	0.475	0.070	0.610	0.086	0.315	0.138	0.382	0.113
Effective seasonal rainfall, inches	20.51		11.48		12.71		19.81		15.76	

**Andropogon scoparius* was the dominant type of vegetation growing on this area.

TABLE 2.—*Data on the total calcium and phosphorus content of unfertilized alfalfa and effective seasonal rainfall.*

Plat No.	Percentage of calcium and phosphorus and date harvested											
	May 5 1932		July 7, 1932		Aug. 18, 1932		May 27, 1933		June 26, 1933		Sept. 16, 1933	
	Ca	P	Ca	P	Ca	P	Ca	P	Ca	P	Ca	P
1	2.160	0.113	1.071	0.145	1.790	0.139	1.625	0.175	1.772	0.139	1.462	0.239
2	2.008	0.126	1.241	0.146	1.655	0.124	1.560	0.173	1.965	0.130	1.329	0.222
3	2.290	0.129	1.080	0.141	1.848	0.136	1.625	0.178	1.800	0.140	1.400	0.219
4	2.205	0.115	1.260	0.151	1.915	0.151	1.540	0.169	1.865	0.132	1.274	0.239
5	2.270	0.118	1.095	0.157	1.620	0.156	1.480	0.170	1.820	0.135	1.381	0.219
Average	2.186	0.120	1.149	0.148	1.766	0.141	1.566	0.173	1.844	0.135	1.369	0.228
Effective seasonal rainfall, inches	3.56		6.62		4.82		8.31		2.00		5.30	

of total calcium, while the second crop harvested from the same plats contained only 1.15% of total calcium. The first crop of alfalfa was harvested on May 25 and the effective rainfall from January 1 to May 25 was 3.56 inches, the majority of which fell during January and February. March and April were very dry and no effective rain occurred until May 3. The calcium content of this crop was high. The effective rainfall between the time the first crop was harvested and the date of the second cutting of hay was 6.52 inches. The calcium content of the second cutting of hay was very low. Although variations occur in the calcium content of the alfalfa obtained from different plats, these data indicate that during dry seasons the total calcium content of plants is higher than during periods when the soil contains an abundant supply of moisture for crop growth.

The average total phosphorus content of the alfalfa hay was 0.120% for the first cutting in 1932 and 0.228% for the third cutting in 1933. In 1932 the second crop of alfalfa was higher in total phosphorus than the first cutting, while in 1933 the second cutting of hay was much lower in total phosphorus than the first cutting.

Although the mathematical correlation between the actual amount of rain and the phosphorus in the alfalfa hay is not high, the figures show that the phosphorus content of alfalfa fluctuates with the rainfall; and that the calcium content of the hay is inversely proportional to the quantity of effective rainfall which occurs. The moisture requirement of crops is affected by the temperature and humidity of the atmosphere; consequently, total rainfall could influence plant growth quite differently depending upon whether high rainfall occurs during the spring or summer months. A greater variation in the calcium and phosphorus content of alfalfa occurred between the rainfall and the different cuttings of hay harvested in 1932 than in the hay harvested in 1933. During the season of 1932 the period of high rainfall was in May and June, while in 1933 the period of high rainfall was in March, April, and May.

Additional information which has been obtained from other studies made in this laboratory indicate that small grain and prairie hay are frequently low in phosphorus and calcium when grown on soils which are low in those elements; however, many soils which contain an abundant supply of plant food produce forage crops which are deficient in calcium or phosphorus due to the effect of seasonal conditions on plant development. This is especially important in semiarid regions where the plant food content of the soil is seldom a limiting factor in crop production.

A comparison of the effective seasonal rainfall and the average phosphorus and calcium content of fertilized and unfertilized mature prairie hay is shown in Fig. 2. A similar comparison for alfalfa hay is shown in Fig. 3. The fertilized plants were collected from plats fertilized with phosphate at the rate of 100 to 500 pounds per acre. Since these samples were taken from a large number of plats with different rates in the fertilizer application, it would be difficult to show the exact treatment for each plat, hence the plats that received some fertilization with phosphates were used in this study.

Figs. 2 and 3 show that the addition of plant food to the soil does not produce an appreciable change in the effect of soil moisture conditions on the percentage of calcium and phosphorus in the plant. The addition of phosphorus fertilizers to the soil increased the phosphorus content of all crops of prairie hay except in 1932 and 1933.

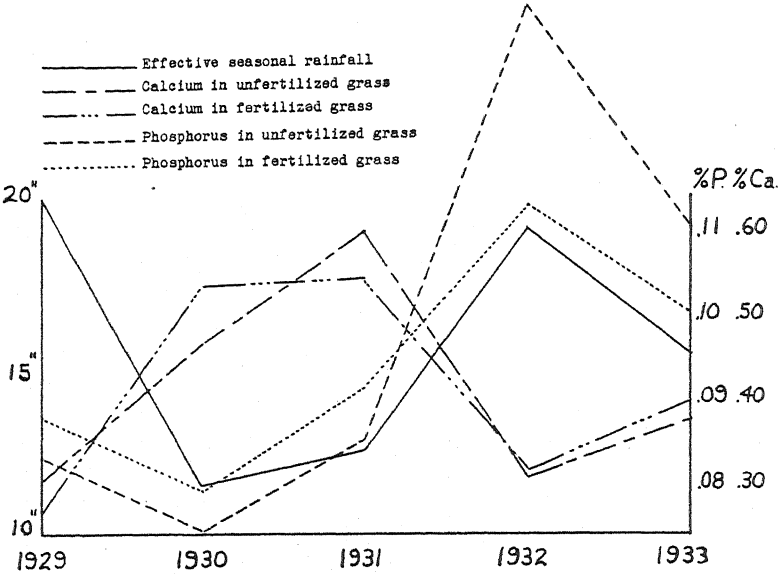

FIG. 2.—The relation between the effective seasonal rainfall and the total calcium and phosphorus content of native prairie hay.

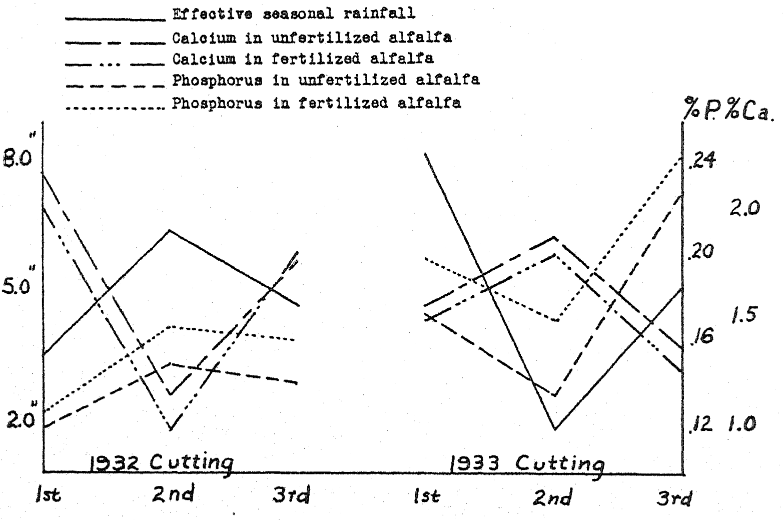

FIG. 3.—The relation between the effective seasonal rainfall and the total calcium and phosphorus content of alfalfa.

The data on calcium was irregular in case of the prairie hay, but was lower in the alfalfa produced on the fertilized plats than in that which grew on the unfertilized area. Apparently calcium applied to the soil as calcium sulfate cannot be used as readily by plants as calcium combined with a weaker anion.

SUMMARY

Thirty samples of little blue stem (*Andropogon scoparius*) were collected each season for 5 years from Kirkland loam soil. Twenty of these samples were taken from plats that were fertilized each year with commercial fertilizer and 10 of the samples were obtained from unfertilized areas. Sixty-eight samples of alfalfa hay were collected from a brown sandy loam, similar to the Bates series of soils, at each cutting for 2 years. Forty-eight samples were taken from plats that were fertilized with commercial fertilizer and farm manure, and 20 samples were obtained from unfertilized soil.

The native grass and alfalfa samples were analyzed for total calcium and phosphorus, and these elements were correlated with the effective seasonal rainfall. During periods when the rainfall was high the calcium content of the plants decreased and the phosphorus content increased. When the effective rainfall was low, the calcium content of the plants increased and the phosphorus content decreased. A knowledge of differences which occur in plant composition is important since mineral deficiencies may or may not be present in forage produced on the same soil during different seasons.

LITERATURE CITED

1. ASTON, B. C. Mineral content of pastures research. N. Z. Jour. Agr., 41 : 90. 1930.
2. ARCHIBALD, J. G., NELSON, P. R., and BENNETT, E. A three-year study of the chemical composition of grass from plants fertilized and grazed intensively. Jour. Agr. Res., 45: 627. 1932.
3. BURKE, EDMOND, NYGARD, IVES J., and MARTIN, WILLIAM MCK. Experiments with phosphorus fertilizers on Montana soils. Mont. Agr. Exp. Sta. Bul. 280. 1933.
4. CAPEN, RUTH G., and LECLERC, J. A. Chemical composition of native Alaskan hays harvested at different periods of growth. Jour. Agr. Res., 46 : 665. 1933.
5. DANIEL, HARLEY A. A study of certain factors which affect the calcium, phosphorus, and nitrogen content of prairie grass. Proc. Okla. Acad. Sci., 12 : 42. 1932.
6. ————. The calcium, phosphorus, and nitrogen content of grasses and legumes and the relation of these elements in the plants. Jour. Amer. Soc. Agron., 26 : 496. 1934.
7. ECKLES, C. H., BECKER, R. B., and PALMER, L. S. A mineral deficiency in the rations of cattle. Minn. Agr. Exp. Sta. Bul. 229. 1926.
8. ELLENBERGER, H. B., NEWLANDER, J. A., and JONES, C. H. Yield and composition of pasture grass. Vt. Agr. Exp. Sta. Bul. 295. 1929.
9. FERGUSON, W. S. III. The seasonal variation in the mineral content of pasture with particular reference to drouths. Jour. Agr. Sci., 21 : 233. 1931.
10. GRUNDER, MAYNARD S. Yield and chemical composition of certain pasture crops, fertilized and unfertilized. Jour. Agr. Res., 46 : 375. 1933.
11. HARTWELL, BURT L. The percentage of total phosphorus in flat turnips as influenced by the amount available in soils. R. I. Agr. Exp. Sta. Bul. 154. 1913.

12. Holtz, Henry F. Effect of calcium and phosphorus content of various soil series in western Washington upon the calcium and phosphorus composition of oats, red clover, and white clover. Wash. Agr. Exp. Sta. Bul. 243. 1930.
13. McCreary, O. C. Wyoming forage plants and their chemical composition. Wyo. Agr. Exp. Sta. Bul. 184. 1931.
14. Orr, J. B. Minerals in Pastures and Their Relation to Nutrition. London : H. K. Lewis and Co. Ltd. 1929.
15. Pittman, D. W. Effect of manure and of phosphorus fertilizer on the yield and composition of alfalfa hay. Utah Agr. Exp. Sta. Bul. 247. 1934.
16. Sotola, Jerry. Relation of maturity to the nutritive value of first, second, and third cuttings of irrigated alfalfa. Jour. Agr. Res., 35 : 361. 1927.
17. Weiser, V. L. Fixation and penetration of phosphates in Vermont soils. Vt. Agr. Exp. Sta. Bul. 356. 1933.
18. Welton, F. A. Fertilizing permanent pastures. Ohio Agr. Exp. Sta. Bimonthly Bul. 165. 1933.
19. Woodman, H. E., D. B. Norman, and M. H. French. VII. The influence of the intensity of grazing on the yield, composition and nutritive value of pasture herbage. Jour. Agr. Sci., 21 : 267. 1931.

THE RESIDUAL EFFECT OF ALFALFA CROPPING PERIODS OF VARIOUS LENGTHS UPON THE YIELD AND PROTEIN CONTENT OF SUCCEEDING WHEAT CROPS[1]

W. H. METZGER[2]

THE beneficial effect of legume crops on nonlegumes grown in rotation has long been appreciated. The duration of such beneficial effects and the extent to which the length of the cropping period for a perennial legume influences the residual effect have been less definitely determined. Mirimanian (4)[3] reported a favorable influence from a "prolonged period of cropping to alfalfa" on the yield of succeeding cotton crops in Armenia which was quite pronounced for 3 years. After that the residual effect declined rapidly. Nicol (5) presented data showing the effects of 20 years of previous cropping with eight legumes at the Rothamsted Experiment Station upon succeeding wheat crops. Alfalfa produced the greatest increases in wheat yields and the effect lasted for periods ranging from 5 to 12 years.

An experiment designed to show the nature and extent of duration of the residual effect of alfalfa upon succeeding wheat crops has been in progress at the Kansas Agricultural Experiment Station since 1922. At that time 26 plats, each 1/20 acre in size, were established on land cropped for many years previously to grain crops. Of these 26 plats, 17 were seeded to alfalfa and the remaining 9 seeded to wheat. It was originally planned to plow up one plat of alfalfa sod each year, but after plowing one such plat in 1923 the plan was changed and thereafter duplicate plats were plowed each summer. The last two alfalfa plats were plowed in 1931 and seeded to wheat and since that time the entire area has been cropped uniformly. Beginning with plat No. 2, every third plat has been cropped to wheat continuously. The soil is a silt loam of moderate fertility and the average annual precipitation is 31 inches.

In this experiment the length of time alfalfa occupied the soil varied from 1 to 9 years. Also, the length of time wheat has been continuously cropped on plats on which alfalfa was grown previously has varied from 3 to 11 years. The yields of the plats continuously cropped to wheat were plotted for each year on graph paper and the points thus established were connected. From such a broken line the yields corresponding to continuous cropping to wheat were determined for the plats previously cropped to alfalfa and by comparison with the actual yields for such plats the increases or decreases oc-

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[2] Assistant Professor of Soils. The field experiment from which the data presented were derived was initiated by Prof. R. I. Throckmorton and successively supervised by Prof. E. S. Lyons, Dr. F. L. Duley, and the writer. Grateful acknowledgement is made for these contributions and for valuable suggestions and criticisms by Prof. H. H. Laude regarding the statistical treatment of the data.

[3] Figures in parenthesis refer to "Literature Cited," p. 659.

casioned by alfalfa cropping were calculated. In Fig. 1 the increases and decreases presumably attributable to previous cropping with alfalfa are shown as bushels of wheat per acre.

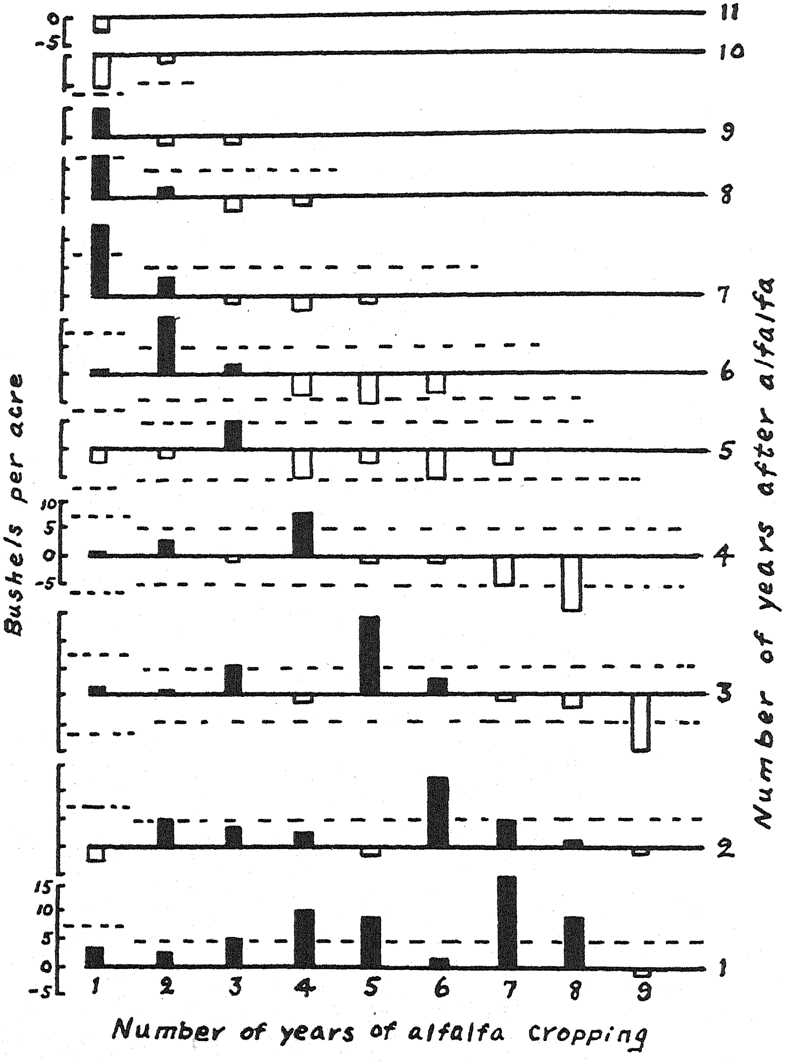

FIG. 1.—Increases and decreases of wheat yields occasioned by previous alfalfa cropping periods of various lengths. Solid blocks indicate increases: open blocks indicate decreases. Broken lines indicate the magnitude of the standard error of the experiment.

Two factors may be prominently active in determining the response of a succeeding crop to the residual effect of alfalfa cropping, i. e., (a) nitrogen supply, and (b) moisture supply. Other factors doubtless are operative in varying degrees. It has been shown by

Duley (1) and by Kiesselbach, Russel, and Anderson (3) that alfalfa very thoroughly depletes the soil moisture supply to considerable depth, and that in regions where rainfall is frequently a limiting factor in crop production, the residual effect on succeeding crops as a result of moisture depletion may become very pronounced. In continuous wheat cropping, where a fallow period of over two months intervenes between harvest and planting time each year, the moisture factor may be of little significance except immediately following the breaking of the alfalfa sod. On the other hand, available nitrogen is ordinarily increased following the plowing under of an alfalfa sod and on soils deficient in available nitrogen this factor tends toward increased yields of succeeding crops.

The yield performance of the wheat crops following alfalfa in this experiment has been somewhat erratic. The interaction of the two factors listed in the preceding paragraph, provided moisture deficiency resulted from previous alfalfa cropping, would tend to produce this result. Another factor which unfortunately has seriously affected the results was the development of foot-rot diseases. This condition was first noticed in 1927, was less prevalent in 1928, became very serious in 1929, was almost wholly absent in 1930, and was only slightly injurious in 1931, while in 1932, 1933, and 1934 the disease was a serious detrimental factor over the entire experiment. It is difficult, therefore, to evaluate the influence of alfalfa on wheat yields in this experiment in 1927, 1929, 1932, 1933, and 1934. Also the diseases, while present in all plats, were distinctly more prevalent during the years 1932, 1933, and 1934 in those plats which had produced alfalfa previous to wheat than in those which produced wheat continuously.[4]

In spite of these diseases, however, the alfalfa appears to have produced conditions tending toward increased wheat yields which extended over a period of several years. The tendency toward uniform increases in yields was confined largely to the first two years of wheat cropping following the various alfalfa cropping periods. However, the year 1930, which was favorable from the standpoint of moisture and temperature conditions and in which diseases were not prevalent, showed increased wheat yields for all plats on which alfalfa grew previously as compared to plats continuously cropped to wheat. This was true regardless of the length of the alfalfa cropping period or the period of wheat cropping following alfalfa. These increases tended to be greater with the longer periods of alfalfa cropping. In those cases where yields were decreased, it is impossible to say to what extent the decreases resulted from residual moisture deficiency or from differential distribution of diseases. Comparative studies of precipitation records and the wheat yields from this experiment point rather definitely toward diseases as the controlling factors.

The standard error of the experiment, determined by the analysis of variance, was ± 6.8 bushels as applied to single plats and

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[4] This conclusion is based on field observations of the writer and on charts of the area prepared by Dr. Hurley Fellows, Pathologist of the Division of Cereal Crops and Diseases, U. S. Department of Agriculture.

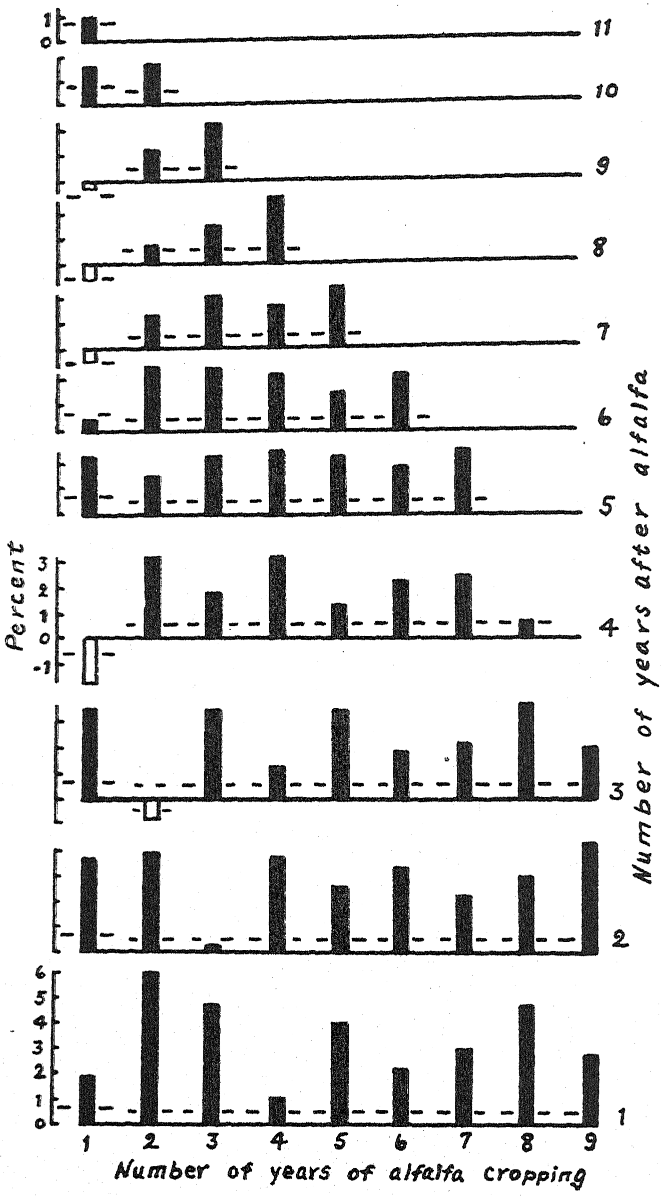

FIG. 2.—Increases and decreases of protein content of wheat occasioned by previous alfalfa cropping periods of various lengths. Solid blocks indicate increases; open blocks indicate decreases. Broken lines indicate the magnitude of the standard error of estimate.

± 4.8 bushels as applied to duplicated plats. These values are indicated in Fig. 1 by the horizontal, broken lines. According to this measure, many of the increases and decreases of yield are of doubtful significance.

The increases and decreases in protein content of the wheat crops resulting from previous cropping to alfalfa are shown in Table 1 and in Fig. 2.

These increases and decreases in protein content were determined on the basis of the regression of protein content upon yield from the plats continuously cropped with wheat. The correlation of protein content with yield from plats so cropped, based on 91 pairs of values from single plats covering a period of 11 years, was $r = -.809 \pm .024$. The data were plotted in Fig. 3, which shows the scatter of the dots about the regression curve. The regression is clearly not linear. The curve was fitted to the data according to the method for fitting a free hand curve described by Ezekial (2). The equation, $\log y = 5.8913 - 4.2369 \log x$, closely approximates the curve.

From the regression curve the protein content corresponding to each yield for plats on which alfalfa was previously grown was estimated. By subtracting each of these values from the corresponding actual protein content, the increases presented in Table 1 were obtained. The use of the regression curve for determination of the values to be compared with the actual protein content data probably largely eliminated the influence of the foot-rot diseases. This statement is based on an assumption that such diseases would prob-

TABLE 1.—*Increases and decreases of protein content of wheat attributable to previous cropping of the land to alfalfa.**

No. years cropped with alfalfa	Increase or decrease in percentage of protein for the year indicated, following the breaking of alfalfa sod										
	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	11th
1	2.00†	3.65†	3.50†	—1.70†	2.20†	0.50†	—0.60†	—0.50†	—0.25†	1.60†	1.05†
2	5.98	3.85	—0.80‡	3.17	1.50	2.45	1.27	0.73	1.23	1.67	—
3	4.88	0.23	3.52	1.75	2.25	2.42	1.95	1.47	2.32	—	—
4	1.15	3.65	1.30	3.17	2.40	2.27	1.75	2.67	—	—	—
5	4.00	2.60	3.47	1.30	2.27	1.57	2.35	—	—	—	—
6	2.23	3.20	1.82	2.15	1.90	2.25	—	—	—	—	—
7	3.10	2.22	2.17	2.35	2.60	—	—	—	—	—	—
8	4.77	2.97	3.67	0.63	—	—	—	—	—	—	—
9	2.93	4.27	2.22	—	—	—	—	—	—	—	—

*Average of duplicate plats except where otherwise noted.
†Based on results from one plat only.
‡Decreases are preceded by a negative sign (-).

ably tend to increase the protein content in about the same proportion to the reduction in yield as was established in the regression curve. The writer knows of no experimental work in which factors have been so segregated as to permit of verification of this assumption.

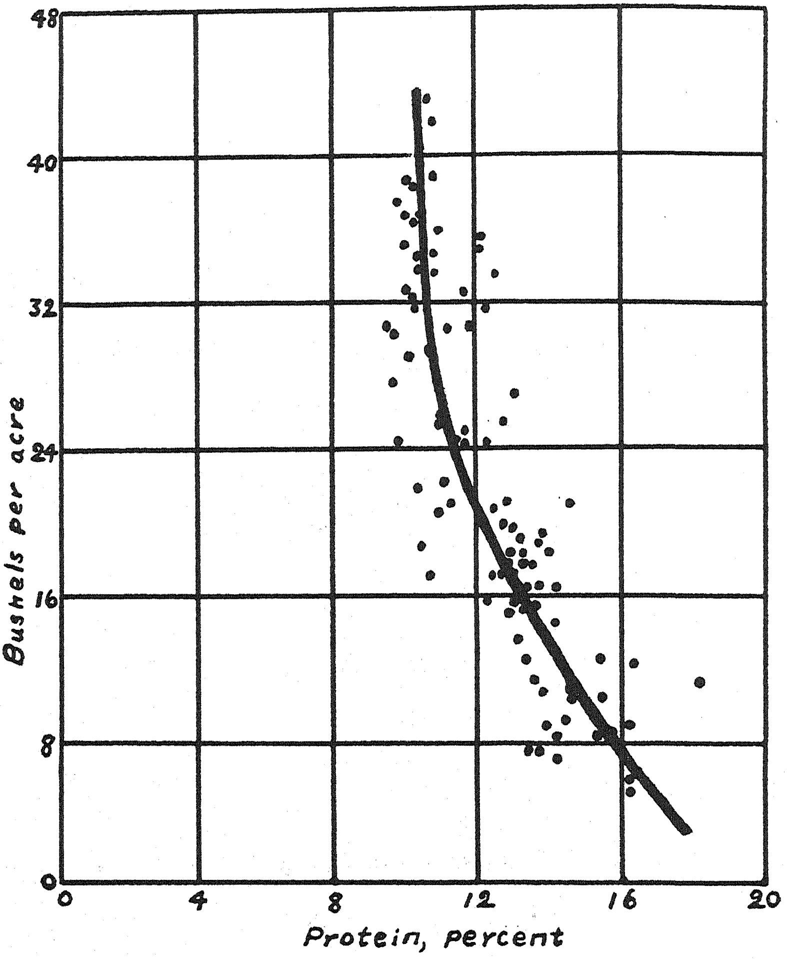

FIG. 3.—Protein content-yield regression curve for wheat produced in continuous culture.

The fact that increases so calculated for years in which foot-rots were largely or wholly absent compare favorably with those for years when the diseases were very prevalent lends weight to the validity of crediting the increases for the latter group of years wholly to the influence of the alfalfa crop.

The protein content data indicate quite consistent and, for the most part, highly significant increases attributable to the alfalfa. The broken horizontal lines in Fig. 2 indicate the magnitude of the standard error of estimate as applied to the estimated protein contents derived from the regression curve. The standard error of estimate as determined for data from single plats was ± .69%. As applied to averages of duplicated plats this value was ± .488, hence the shift in the broken lines in the graph to the right of the first vertical column. Most of the increases exceed twice these values.

The protein data indicate that the residual effect of alfalfa, especially if the crop is allowed to remain on the soil 2 or more years, may be reflected in succeeding crops for a period of at least 10 years under the climatic and soil conditions represented by this experiment. Whether this effect reaches a maximum before or at the completion of 9 years of cropping with alfalfa is not revealed by the data. The effect of from 1 to 3 years of alfalfa, however, seems definitely to be decreased after 9 years or more of continuous wheat.

Seasonal effects are apparent in the data. The year 1927 was characterized by very high rainfall in June, and only small protein increases, along with some decreases, are creditable to alfalfa for that year. In 1933 and 1934 the June rainfall was very low and protein values for wheat on the alfalfa plats were decidedly in excess of those for the continuous wheat plats.

SUMMARY

An attempt has been made at the Kansas Agricultural Experiment Station to measure the residual effect of alfalfa cropping upon yield and protein content of succeeding wheat crops.

Foot-rot diseases seriously limited the value of the yield determinations in certain years after the third wheat crop of the experiment. When these diseases were absent, alfalfa produced favorable effects on yields of succeeding wheat crops. When the diseases were prevalent continuously cropped wheat plats produced the larger yields. An attempt was made to eliminate this factor in the evaluation of the protein data. All periods of alfalfa cropping, varying from 1 to 9 years, produced increases in protein content of wheat.

Alfalfa cropping for as short a period as 2 years produced a favorable residual effect measurable by succeeding wheat crops over a period of at least 8 years. The longer periods of alfalfa cropping produced greater residual effects. Whether the maximum was reached in less than 9 years of alfalfa cropping the data do not clearly reveal.

It appears that residual effects may continue to be manifested longer in protein content than in yield. Diseases in the wheat in this experiment, however, have not permitted a clear verification of this statement.

LITERATURE CITED

1. Duley, F. L. The effect of alfalfa on soil moisture. Jour. Amer. Soc. Agron., 21 : 224–231. 1929.
2. Ezekial, Mordecai. Methods of Correlation Analysis. New York: John Wiley & Sons, Inc. 1930.
3. Kiesselbach, T. A., Russel, J. C., and Anderson, Arthur. The significance of subsoil moisture in alfalfa production. Jour. Amer. Soc. Agron., 21 : 241–268. 1929.
4. Mirimanian, K. P. The duration of the favorable influence of alfalfa on the cotton fields of Armenia. Jour. Amer. Soc. Agron., 26 : 475–480. 1934.
5. Nicol, Hugh. Rothamsted experiments on residual value of legume crops. Empire Jour. Exp. Agr., 1 : 22–32. 1933.

EFFECT OF SOIL TEMPERATURE AND DEPTH OF PLANTING ON THE EMERGENCE AND DEVELOPMENT OF SORGHUM SEEDLINGS IN THE GREENHOUSE[1]

J. H. Martin, J. W. Taylor, and R. W. Leukel[2]

SORGHUMS are of tropical origin and have long been known to germinate and grow best at relatively high temperatures. Both seeds and seedlings of sorghum are very sensitive to environmental conditions. Experiments are under way to determine the causes of seed rotting and seedling blights of sorghums and the soil temperature and other factors influencing them. Data were recorded on the germination and development of sorghum seedlings grown at five soil temperatures and three depths of planting in one of the pathological experiments, and these data are presented here.

MATERIAL AND METHODS

The varieties studied were Standard feterita, Dwarf Yellow milo, Dawn kafir, and White Italian broomcorn, each being representative of rather distinct groups. Feterita has large, soft, starchy seeds that germinate quickly but are subject to rotting in cold wet soil. The seedlings also are rather large and the plants mature early. The milo seeds and seedlings are somewhat smaller than those of feterita and the seeds usually germinate slightly slower and are less subject to rotting. Milo matures later than feterita. Kafir seeds are smaller and harder than those of milo, germinate more slowly, and are less subject to rotting in the field. The seedlings are much smaller than those of milo and the plants mature later. Broomcorn seeds are hard and germinate slowly. They are usually enclosed in the glumes and are fairly resistant to rotting under field conditions. The seedlings are somewhat larger than those of Dawn kafir and the plants mature in about the same period.

The seeds were planted on March 26, 1930, in the greenhouse at the Arlington Experiment Farm, Rosslyn, Va., near Washington, D. C. Local soil containing 1 part in 4 of leaf mold was used and the moisture content was maintained at about 60% of the maximum water-holding capacity. The seeds in half of the cans were untreated, but the remainder were dusted with copper carbonate. The soil temperature control equipment used, except for minor modifications, has already been described.[3] The soil temperatures were maintained at approximately 15°, 20°, 25°, 30°, and 35° C, and seeds were planted at ½-, 1½-, and 2½-inch depths.

The data here presented are based upon determinations in a total of 144 soil cans planted at the rate of 25 seeds per can. There were five temperatures, three planting depths, and two seed treatments of each of four varieties, requiring a total of 120 soil cans. The re-

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[1] Contribution from the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture. Received for publication May 22, 1935.

[2] Senior Agronomist, Associate Agronomist, and Associate Pathologist, respectively.

[3] Leukel, R. W. Equipment and methods for studying the relation of soil temperature to diseases in plants. Phytopath., 14 : 384–397. 1924.

maining 24 cans were a duplication of the 15° C soil temperatures, sterilized soil having been used. Germination and stage of growth were recorded daily. The other measurements were taken approximately when the plants had reached the 5-leaf stage. The plant measurements are averages of 10 plants in each can except in a few cases where the total number of available plants was less.

RESULTS OBTAINED

Data secured were percentage of germination, date of emergence, increase in number of leaves, lengths of the coleoptile and subcrown internode, and numbers of crown roots and subcrown rootlets. The figures presented represent averages for all treatments of each variety or for all varieties at each treatment. Data from the $CuCO_3$-treated seeds were averaged with those from the untreated seeds. The data from the plants in the steam-sterilized soil were averaged with those grown in unsterilized soil at the same temperature (15° C), except in the case of germination percentages which were affected favorably by soil sterilization.

VARIETAL DIFFERENCES

The average measurements recorded on emergence and development of each of the four varieties are shown in Table 1. The germination of the Dawn kafir seeds was weaker and slower than that of other varieties. The differences in growth rate after emergence were not important. The average coleoptile length was proportional to the size of the seedlings of the four varieties, Standard feterita having the longest and Dawn kafir the shortest. The broomcorn and feterita plants had the longest subcrown internodes, and the broomcorn plants had the most numerous roots.

TABLE 1.—*Measurements of germination and plant parts of four sorghum varieties.**

Variety	Germination %	Time of emergence, days†	Emergence to 4-leaf stage, days*	Coleoptile length, mm	Subcrown internode length, mm	Crown roots, number	Subcrown rootlets, number
Standard feterita...	72	6.3	14.4	11.3	42.7	2.5	2.4
Dwarf Yellow milo..	78	6.4	17.8	9.3	36.9	2.6	3.4
Dawn kafir.........	65	9.1	15.1	6.6	36.2	2.0	3.8
White Italian broomcorn...........	86	7.2	16.0	8.9	44.0	3.1	4.4

*Average of all treatments.
†Majority of plants.

EMERGENCE

The rate of and time for emergence and the period from emergence to the 4-leaf stage at different soil temperatures and depths of planting are shown in Table 2. There was a decrease in the average germination percentage at the temperatures below 25° C. The seeds planted at a depth of 2½ inches showed almost as high an average germination as at the shallower depths of planting, but there was a distinctly low germination from deep planting at the cool 15° C temperature. The seedlings emerged from the 1½ and 2½ inch depths of planting about as quickly as from the ½-inch planting except at the 15° temperature, where there was a noticeable difference. Emergence was delayed distinctly at soil temperatures below 25° C. The period between emergence and the 4-leaf stage increased progressively from 9 to nearly 24 days as an average, as the soil temperatures dropped from 35° to 15° C. This shows an effect on plant growth by soil temperature where the air temperature was uniform for all soil treatments. Differences in rapidity of development at the three planting depths were small and unimportant.

TABLE 2.—*Rate and time of emergence of sorghum seedlings from planting at three depths in each of five soil temperatures.**

Depth of planting, inches	Soil temperature, °C					
	15°	20°	25°	30°	35°	Average
	Rate of Emergence %					
0.5	71.0	80.5	79.0	77.0	82.0	79.9
1.5	58.0	75.0	80.0	83.5	82.5	79.0
2.5	56.5	72.5	78.5	82.0	74.0	75.1
Average	61.8	76.0	79.2	80.8	79.5	—
	Time of Emergence, Days					
0.5	6	7	5	4	4	5.2
1.5	9	8	4	4	4	5.8
2.5	11	8	5	4	5	6.6
Average	8.7	7.7	4.7	4.0	4.3	—
	Time from Emergence to 4-leaf Stage, Days					
0.5	22	15	12	11	9	13.8
1.5	24	14	13	10	9	14.0
2.5	25	16	12	11	9	14.6
Average	23.7	15.0	12.3	10.7	9.0	—

*Average of four varieties.

SEEDLING DEVELOPMENT

The effect of soil temperature and depth of planting upon the length of the coleoptile and subcrown internode and upon the number of crown roots and subcrown rootlets is shown in Table 3. The length of the coleoptile decreased slightly with an increase in soil temperature and with decreased planting depth. The coleoptile does not grow all the way upward from the seed because most of the elongation takes place in the subcrown internode (Fig. 1) below the coleoptile. The base of the coleoptile is thus pushed up nearly to or even above the soil surface. The length of the subcrown internode thus depends largely upon the depth of planting, as the data indicate. The internode length is seen to be directly proportional to the depth of planting. The subcrown internodes were considerably longer at soil temperatures above 20° than at 20° or 15° C. This greater elongation forced the base of the coleoptile above the soil surface at high temperatures and necessitated the formation of the crown and the first growth of crown roots in the air (Fig. 1, 3).

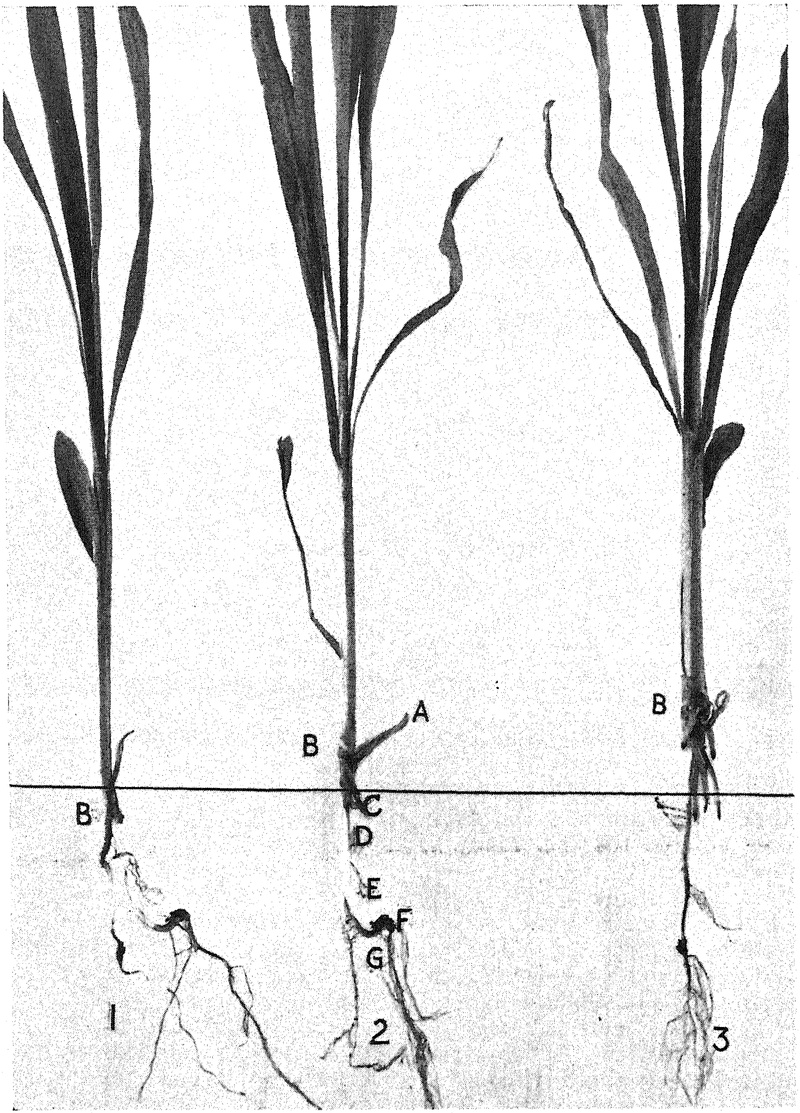

FIG. 1.—Feterita seedlings planted at a depth of 1 inch in soil at 15° (1), 20° (2), and 25° C (3). The horizontal line shows the location of the soil surface. (a) Coleoptile, (b) crown, (c) crown roots, (d) subcrown internode, (e) subcrown rootlet, (f) seed, (g) seminal root. Note the difference in the length of subcrown internode and height of crown due to soil temperature differences. Sorghums produce only a single seminal root.

TABLE 3.—*Length of coleoptile and subcrown internode and number of roots on sorghum seedlings from planting at three depths at each of five soil temperatures.**

Depth of planting, inches	Soil temperature, °C 15°	20°	25°	30°	35°	Average
	Coleoptile Length, mm					
0.5	8.6	8.5	9.4	8.2	6.9	8.4
1.5	9.7	9.7	9.4	7.9	6.9	8.8
2.5	11.0	10.2	9.5	8.4	7.3	9.3
Average	9.9	9.5	9.4	8.2	7.0	—
	Subcrown Internode Length, mm					
0.5	16.1	17.5	25.0	26.1	22.0	21.6
1.5	31.4	38.5	40.9	42.9	40.7	38.8
2.5	52.3	63.2	67.3	68.5	68.9	64.2
Average	33.3	39.8	44.4	45.9	43.9	—
	Crown Roots, Number per Plant					
0.5	2.7	3.2	2.2	2.8	3.4	2.8
1.5	2.1	2.9	2.5	2.6	3.4	2.7
2.5	1.3	2.7	2.7	2.4	2.9	2.4
Average	2.0	2.9	2.5	2.6	3.2	—
	Subcrown Rootlets, Number per Plant					
0.5	0.7	0.8	1.0	1.3	1.6	1.0
1.5	1.7	3.0	3.2	5.0	4.7	3.5
2.5	4.6	5.8	6.9	7.8	7.6	6.5
Average	2.3	3.1	3.7	4.7	4.6	—

*Average of 4 varieties.

The depths of planting of approximately 13, 38, and 63 mm are less than the average internode length and suggest that a majority of the plants at soil temperatures of 25° C or higher formed crowns above the surface of the soil. Crown roots grew downward until they entered the soil. Many of the subcrown internodes were so flexible that the weight of the seedling forced the crown down to the surface of the soil. Under field conditions such high crowning, even at high temperatures, is not observed frequently because the washing and drifting of the soil tend to fill up the planter furrows and thus cover the crowns. Lack of light also causes the subcrown internode to be abnormally long.[4]

There was some indication of fewer crown roots and a distinct tendency for fewer subcrown rootlets as the soil temperatures decreased. Deep planting tended to reduce the number of crown roots but greatly increased the number of subcrown rootlets. Sorghum

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[4] HAMADA, H. Wachstumverhältnisse der Keimorgane von verschiedenen Gramineen im Dunkel und Belichtung mit besonderer Berücksichtigung ihrer systematischen Stellung. Mem. Col. Sci., Kyoto Imp. Univ., Ser. B, 19 : 71–128. 1933.

plants produce only a single seminal root (Fig. 1).[5] Until crown roots are formed, the plants must secure their soil nutrients from the single root and the subcrown rootlets. The subcrown internode is longest from deep planting at high soil temperatures. The greater length of the subcrown internode where rootlets can develop may account largely for the greater number of subcrown rootlets from deep planting and high soil temperatures.

SUMMARY

The percentage and rapidity of germination in sorghums were reduced by soil temperatures below 25° C and slightly reduced by deep planting (2½ inch). Seedling development was retarded by lower soil temperatures within the range from 35° to 15° C. Development also was retarded by deep planting at 15° C soil temperatures but not at higher temperatures.

The length of the coleoptile of sorghum seedlings was greatest in varieties producing large seedlings and was increased slightly by deep planting and low soil temperatures.

The length of the subcrown internode varied directly with the depth of planting and was increased by soil temperatures above 25° C. At high soil temperatures, many of the seedlings formed their crowns above the soil surface.

The number of crown roots was generally greatest from shallow planting at high soil temperatures.

The number of subcrown rootlets was greatest from deep planting at high soil temperatures.

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[5] SIEGLINGER, J. B. Temporary roots of the sorghums. Jour. Amer. Soc. Agron., 12 : 143–145. 1920.

THE DECREASE IN YIELDING CAPACITY IN ADVANCED GENERATIONS OF HYBRID CORN[1]

N. P. NEAL[2]

THE exclusive use of first generation seed for the production of hybrid corn runs counter to the traditional practice of the farmer who is accustomed to saving his own supply. The generally superior performance of tested and adapted hybrids greatly enhances the temptation to take seed from the crop; and, in some cases at least, the rather attractive appearance of the advanced generations themselves tends to mask the decline in productivity which has occurred. As a basis for efficient practice, it is important, therefore, that a well-founded body of fact be established concerning the value of first generation hybrid seed as compared with that taken from later generations.

Wright (4)[3] has pointed out that "a random-bred stock derived from n inbred families will have $\frac{1}{n}$th less superiority over its inbred ancestry than the first cross or a random-bred stock from which the inbred families might have been derived without selection." The main object of the present study was to determine whether, on the average, this generalization holds for corn and to ascertain if, in particular cases, the departures from it were large enough to be significant in practice.

Tests were made in 1933 and 1934 to determine the relative yielding capacities of the first and succeeding generations of hybrid strains. In the first season's trials, precautions were not taken to avoid competition effects between the F_1 and F_2 generations. The present report involves only the data obtained in 1934.

MATERIALS AND METHODS

The material used in the test consisted of 10 single, 4 three-way, and 10 double hybrids and their F_2 generations, as well as the F_3 generations of 8 of the single and 3 of the three-way hybrids. Reference to Table 1 shows the various hybrids comprising the same group of inbred lines. Lines 25 and 26 are closely related.

The F_2 seed of certain of the single hybrids was taken from the bulked seed obtained from a series of crossing plats in which the single hybrids were the respective male parents. In these instances the seed used was obviously the result of random pollination. The F_2 seed of some of the three-way and double hybrids, having been harvested from uncontaminated field crops of the respective hybrids, was likewise the product of random pollination. In all other cases the seed

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[1] Contribution from the Departments of Genetics (paper No. 188), Agronomy, and Plant Pathology, Wisconsin Agricultural Experiment Station, Madison, Wis. Published with the approval of the Director of the Station. Received for publication May 31, 1935.

[2] Instructor. The writer desires to express his appreciation to Dr. R. A. Brink, of the Department of Genetics, for helpful suggestions in the preparation of the manuscript.

[3] Figures in parenthesis refer to "Literature Cited," p. 670.

TABLE 1.—*Data on the yield of F_1, F_2, and F_3 generations of single, three-way, and double hybrids.*

	Yield, bus. per acre				Decrease, bus. per acre			Decrease %		
	Actual			Expected	Actual		Expected	Actual		Expected
	F_1	F_2	F_3	F_2 and F_3	F_1–F_2	F_1–F_3	F_1–F_2 or F_3	F_1–F_2	F_1–F_3	F_1–F_2 or F_3
				Single Hybrids						
($3 \times R_3$)	59.2	45.7	52.6	40.4	13.5	6.6	18.8	22.8	11.3	31.75
($R_3 \times 6$)	60.7	47.0	45.2	43.0	13.7	15.5	17.7	22.6	25.5	29.16
($R_3 \times 25$)	61.2	43.7	48.8	41.5	17.5	12.4	19.7	28.6	20.3	32.19
($R_3 \times 26$)	55.4	34.8	—	38.5	20.6	—	16.9	37.2	—	30.50
(3×25)	70.9	41.7	45.7	47.4	29.2	25.2	23.2	41.2	35.5	32.72
(3×26)	68.1	44.7	—	46.3	23.4	—	21.8	34.4	—	32.01
(6×26)	67.6	52.6	50.5	47.9	15.0	17.1	19.7	22.2	25.3	29.14
($M_{13} \times R_3$)	58.4	40.9	42.7	39.7	17.5	15.7	18.7	30.0	26.9	32.02
($R_3 \times 23$)	59.9	44.5	46.0	41.6	15.4	13.9	18.3	25.7	23.2	30.55
(23×26)	66.8	46.5	49.0	46.5	20.3	17.8	20.3	30.3	26.7	30.38
Average	62.8	44.2	47.5	43.3	18.6	15.5	19.5	29.5	24.3	31.05
				Three-way Hybrids						
($R_3 \times 3$) $\times 25$	66.3	49.0	48.5	51.9	17.3	17.8	14.4	26.1	26.9	21.72
(3×25) $\times R_3$	60.9	44.7	48.3	47.8	16.2	12.6	13.1	26.6	20.7	21.51
($R_3 \times 25$) $\times 6$	69.1	56.9	—	55.0	12.2	—	14.1	17.7	—	20.40
(6×25) $\times R_3$	60.7	46.5	45.5	48.3	14.2	12.4	12.4	23.4	25.0	20.43
Average	64.2	49.3	47.4	50.7	14.9	14.3	13.5	23.4	24.2	21.01
				Double Hybrids						
($R_3 \times 6$) (23×25)	64.3	52.0	—	54.7	12.3	—	9.6	19.1	—	14.93
($M_{13} \times R_3$) (6×25)	57.9	50.0	—	49.5	7.9	—	8.4	13.6	—	14.5
($3 \times R_3$) (23×25)	68.1	58.7	—	57.0	9.4	—	11.1	13.8	—	16.29
(6×25) ($3 \times R_3$)	67.6	58.2	—	56.9	9.4	—	10.7	13.9	—	15.83
($23 \times R_3$) (3×25)	60.5	53.6	—	51.4	6.9	—	9.1	11.4	—	15.04
($R_3 \times 6$) (3×25)	65.8	55.1	—	55.6	10.7	—	10.2	16.3	—	15.50
($23 \times R_3$) ($M_{13} \times 6$)	64.0	52.6	—	54.4	11.4	—	9.6	17.8	—	15.00
(3×6) (23×25)	64.5	57.4	—	55.2	7.1	—	9.3	11.0	—	14.42
($R_3 \times 25$) ($M_{13} \times 23$)	62.7	45.2	—	52.9	17.5	—	9.8	27.9	—	15.63
($3 \times R_3$) (6×23)	65.5	56.9	—	55.6	8.6	—	9.9	13.1	—	15.11
Average	64.1	54.0	—	54.3	10.1	—	9.8	15.8	—	15.22

P.E. of F_1 generation = ±1.45 bushels. P.E. F_2 and F_3 generations = ±1.15 bushels.

was obtained from hand pollinations. In each such instance at least 40 sound ears were represented, while the pollen was taken from not less than 20 plants.

In the yield trials each strain was replicated six times in a random fashion, each replicate consisting of two 10-hill rows. Four kernels were planted in each hill with no subsequent thinning. Since competition would be expected to exert an influence in favor of the F_1 generation, the latter was separately randomized, though in the same trial area. Thus, in each of the six series, two sub-series were planted, one to the F_1 generation and the other to the F_2 and F_3 generations. It was not expected that there would be any significant competitive effects between the F_2 and F_3 generations and these were accordingly randomized together.

The ears from each plat were harvested separately, dried to 13% moisture, and weighed. The data were analyzed according to the analysis of variance method by Fisher (1) and the acre yields calculated on a shelled corn basis.

The yields of each of the inbred lines which entered into the composition of the various hybrids were likewise determined in 1933 and 1934 and are shown in Table 2. The lower yields obtained in 1934 may be attributed to the severe drought experienced then. The data on the inbred lines probably represent a fairly reliable estimate of their yielding capacities.

The expected yields of the advanced generations were calculated from those of the parent inbred lines and the respective F_1 generations of the hybrids, using Wright's (4) formula. On this basis, the loss of vigor in the F_2 generation when the F_1 is bred *inter se* will vary in inverse proportion to the number of inbred lines involved and may be stated as $\frac{1}{n}$ of the excess vigor of the hybrid over that of the inbreds, where n equals the number of parent lines in the ancestry of the hybrids. In other words one-half, one-third, and one-quarter of the excess vigor of the F_1 generation over the inbred parents will be lost in the F_2 generation when two, three, or four inbred lines, respectively, comprise the parents of the hybrid. Since zygotic equilibrium is reached in the F_2 generation, there should be no further decrease in vigor in the F_3 and succeeding generations, provided mating is completely random and there is no differential selection.

TABLE 2.—*Comparison of the yields of inbred lines in 1933 and 1934.*

Inbred line	Yield, bus. per acre		
	1933	1934	Average
R3	24.4±0.66	18.8±0.84	21.6
3	29.3±0.79	24.4±1.09	26.8
6	33.9±0.91	31.8±1.42	32.8
23	34.9±0.93	27.9±1.25	31.4
25	24.3±0.65	24.6±1.10	24.4
26	21.8±0.58	24.4±1.09	23.1
M13	23.6±0.62	23.1±1.03	23.3

P.E. of inbred lines = ±2.35 and ±1.08 in 1933 and 1934, respectively.

The P_1 yield values were determined by averaging the yields of the respective parent lines for each single and double hybrid. Since in a three-way hybrid one inbred line constitutes 50% of the parentage, this parent was weighted accordingly in deriving the P_1 average. Given the yield of the respective F_1 generations, it was then a simple matter, using Wright's formula, to calculate the expected yield of the respective F_2 generations.

EXPERIMENTAL DATA

The yields of the hybrids, together with the expected yields of the advanced generations and the actual and expected decreases in these from the F_1 generation are presented in Table 1.

The greatest decline in yield occurs with the single hybrids and amounts, on the average, to 29.5%. The double hybrids show the smallest decrease, averaging 15.8%, or about one-half that observed for the single hybrids. The decrease in yield of the three-way hybrids is intermediate and averages 23.4%. These averages are in close agreement with the calculated averages which are, respectively, 31.05%, 21.03%, and 15.29% for the single, three-way, and double hybrids. The coefficient of variability of the deviations is 13.2%. In part, this degree of variability can be attributed to environmental influences as well as to random sampling. It is possible also that some of the departures result from complex types of gene interactions.

The average yield values of the parent lines of the hybrids involved in this experiment are presented in Table 3, together with the actual and calculated percentages of the loss of excess vigor of the hybrids over the P_1 lines.

TABLE 3.—*Comparing the actual loss of excess vigor of hybrids over their parent inbred lines with the calculated loss.*

	Average yield, bus. per acre		Av. diff. F_1-P_1, bushels per acre	Yield F_2, bus. per acre	
	F_1	P_1		Actual	Expected
10 single hybrids....	62.8	23.74	39.06	44.2	43.3
4 three-way hybrids.	64.2	23.75	40.45	49.3	50.7
10 double hybrids...	64.1	25.00	39.10	54.0	54.3

	Loss of vigor in yield of grain			
	Actual		Expected	
	Bus. per acre	%	Bus. per acre	%
10 single hybrids....	18.6	47.6	19.5	50
4 three-way hybrids.	14.9	36.8	13.5	33.3
10 double hybrids...	10.1	25.8	9.8	25

The average actual loss of excess vigor as represented by yield is 47.6%, 36.8%, and 25.8%, respectively, for single, three-way, and double hybrids as compared with expected losses of 50%, 33.3%, and 25%, respectively.

Since gametic equilibrium is reached when the hybrids reproduce, the F_3 generation should yield the same as the F_2 generation, assuming no differential selection. In the case of the single hybrids in this experiment, the average decrease in yield of the F_2 generation from the F_1 generation was 29.5% as compared with an average of 24.3% for the F_3 generations. The difference in yield between the F_2 and F_3 generations of the three-way hybrids is not statistically significant.

Though no precise determinations were made, the stalks and leaves of the advanced generations seemed to exhibit less decline in vigor than was observed in yield of grain. While the proportion of barren and spindly stalks was larger than for the F_1 generation, the stalks of the advanced generation progenies were almost as tall and as leafy as those of the former. This could be explained on the assumption that the hybrids were homozygous for more of the factors determining these characters than they were for those affecting yield.

DISCUSSION

The results herein reported are clearly indicative of what might be expected when the advanced generations of hybrid strains are grown, as is the case when seed is saved from a hybrid crop.

Kiesselbach (2) reports the comparative yields of the F_1, F_2, and F_3 generations of 21 single hybrids and their parent lines. The second and third generation hybrids averaged, respectively, 68% and 66% as much grain yield as the first generation hybrids. Richey, *et al.* (3), working with 10 double hybrids, showed that the yields of the F_2 generations were from 5.0% to 24% less than those of the F_1 generation, with an average of 15.2%.

The data presented in this paper are in general agreement with the above. The yield of grain of the parent lines of the hybrids averaged from 37% to 39% of that of the F_1 generations, while the F_2 and F_3 generations of single hybrids averaged, respectively, 70.5% and 75.7%. The yield of the F_2 generations of double hybrids averaged 84.2% of the F_1 generation. In the case of the three-way hybrids, the F_2 and F_3 generations averaged, respectively, 76.6% and 75.8% as much as the F_1 generation. The standard, locally adapted, open-pollinated variety included in this trial yielded 53.1 bushels per acre. The average yield of the F_2 generation of the double hybrids was about the same as that of the variety, while that of the three-way hybrids was almost 4 bushels per acre less.

The results are of further interest in demonstrating that in corn the dissipation of the excess vigor of hybrids over the parent inbred lines is probably in accord with the simple genetical rule which Wright has formulated.

LITERATURE CITED

1. Fisher, R. A. Statistical Methods for Research Workers. Edinburgh: Oliver & Boyd. Ed. 3. 1930.
2. Kiesselbach, T. A. The use of advanced generation hybrids as parents of double cross seed corn. Jour. Amer. Soc. Agron., 22 : 614–626. 1930.
3. Richey, F. D., Stringfield, G. H., and Sprague, George F. The loss of yield that may be expected from planting second generation double-crossed corn. Jour. Amer. Soc. Agron., 26 : 196–199. 1934.
4. Wright, Sewall. The effects of inbreeding and cross breeding on guinea pigs. U. S. D. A. Bul. 1121. 1922.

PRELIMINARY REPORT ON RESISTANCE OF ALFALFA VARIETIES TO PEA APHIDS, *ILLINOIA PISI* (KALT)[1]

REGINALD H. PAINTER AND C. O. GRANDFIELD[2]

AN opportunity to study the reaction of different alfalfa varieties to pea aphids presented itself in the spring of 1934 in an alfalfa variety test being conducted on the agronomy farm at the Kansas Agricultural Experiment Station. The most severe outbreak of pea aphids on record for eastern Kansas occurred at that time, bottom fields being almost invariably heavily infested, while on the uplands the infestations were lighter. The unusual feature of the infestation was that the fields were rather uniformly infested. The large number of aphids resulted in a stunting and yellowing of infested fields that brought into sharp relief differences between individual plants. In a 4-year-old alfalfa variety test consisting of 36 varieties, the number of plants showing no injury varied greatly enough to make a noticeable difference in the appearance of the plats. Examination of these plants showed that they were infested by fewer aphids than other plants indicating they may be different from others in the variety.

As far as could be ascertained from the literature, the resistance of different commercial varieties of alfalfa has never been noted, although resistance of individual plants of Grimm and other varieties of alfalfa to pea aphid has been reported.[3] Because of the irregularity with which field infestations of pea aphids occur, limiting the opportunity for a study of the reaction of different alfalfa varieties to the insect, it seems advisable to report the information obtained.

In the alfalfa variety test, consisting of 86 1/20 acre plats, all varieties were duplicated, with the exception of Grimm, which was represented by six plats and Kansas common by 12 plats, as checks. These plats were seeded in the fall of 1930 and as all are not wilt and cold resistant the stands were not all uniform at the time the study was made. To secure a measure of the infestation of the different varieties, 20 sweeps with a standard 1-foot square net were made on each plat. After removal of leaves, trash, and the few other insects present, the aphids were measured in a graduated cylinder and the results recorded in cc. A single 20-cc sample which was counted contained 12,630 aphids. An estimate was also made of the percentage of damage on the different plats on the basis of the visible injury resulting from aphid attack. This injury consisted of the stunting

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[2] Associate Professor of Entomology, Kansas State College, and Assistant Agronomist, Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, respectively.

[3] BLANCHARD, R. A., and DUDLEY, JOHN E., JR. Alfalfa plants resistant to the pea aphid. Jour. Econ. Ent., 27 : 262–264. 1934.

and yellowing of the plants and the estimate took into consideration both the severity of the damage and the number of injured or uninjured plants. The figures are comparative and concern only the varieties in the test. These data are recorded in Table 1. (See also Fig. 1.)

TABLE 1.—*Pea aphids on alfalfa varieties.*

Rank	Variety	Record No.	Av. No. of cc*	Av. % injury†	Av. % stand
1	Ladak	15988	22	10	85
2	Turkestan	86696	40	10	95
3	Turkestan	19301	48	22	95
4	Turkestan	19302	48	17	95
5	Turkestan	19299	48	15	95
6	Turkestan	19303	50	20	95
7	Turkestan	19300	54	22	95
8	Hardistan	—	56	20	95
9	Turkestan	15754	59	20	95
10	Turkestan	19304	61	37	95
11	Hardigan	18777	61	55	40
12	Acc'l Grimm	19305	61	72	10
13	French	19274	63	52	72
14	Hungarian	81438	65	55	47
15	Turkestan	85751	66	15	95
16	*Grimm* (6 plats)	307	66	62	34
17	Blue Ukranian	19315	67	70	12
18	German	91502	67	62	32
19	Hungarian	15706	72	72	22
20	French	19273	77	60	62
21	Utah	15986	76	67	32
22	Argentine	15996	77	80	57
23	Dakota No. 12	15997	79	75	45
24	*Kansas common* (12 plats)	306	79	62	58
25	Utah	15995	80	72	25
26	French	81489	87	62	65
27	Baltic	15989	87	57	47
28	Italian	85994	87	47	60
29	Italian	85995	89	42	60
30	Italian	85993	90	42	60
31	French	81448	92	70	60
32	Cossack	18836	92	40	80
33	French	19225	96	70	70
34	Kansas	308	108	55	92
35	Dakota	16081	110	75	40
36	Turkestan	19316	127	70	92

*Twenty sweeps of a 1-foot square net measured in a graduated cylinder.

†Percentage injury is the visible injury, i.e., weak plants nearly killed in the spring, and curling and stunting of plants, April 17, 1934.

There is a range in the average number of cc of aphids for 20 sweeps from 22 cc for Ladak to 127 cc for Turkestan, F. C. 19316. An examination of the plats showed that the visible injury agreed in general with the results of the sweeping. Most of the plats contained individual plants which were apparently more or less resistant to the aphids. In Ladak there were only a few plants heavily infested or badly injured by aphids. These plants contributed most of the aphids swept from the plats of this variety.

Some variation existed between the duplicate plats of the respective varieties. This is partly due to the method of sampling, which is the only practicable method available. A consideration of the variations which existed in relation to the position of the plats, especially those of Kansas common and Grimm, showed that there were two areas each consisting of several plats where for some reason the number of aphids present was somewhat greater than in the remainder of the plats. This fact, together with the evident differences in stand, explain most of the larger discrepancies. In nearly half of the duplicate plats the difference amounted to 10 cc or less. In Ladak and Turkestan F.P.I. 86696, the duplicates differed by only 2 cc. The important fact is not so much the exact position of the different varieties as it is that some were apparently more resistant than others and that Ladak, a new variety, showed the most resistance. Also the Turkestan varieties grown showed a wide variation in their resistance, but further tests will be necessary to determine their exact positions.

From Table 1 it may be noted that all varieties with stands above 90% had low infestation, with the exception of Kansas 308 and Turkestan F. C. 19316, which had good stands and high infestation. These two strains were also high in pea aphid injury, indicating that the aphids were present and doing damage to the plants. In general, the percentage injury parallels the infestation as measured in cc of aphids. There appears to be one exception to this, Turkestan, F. P. I. 85751, which had little injury and a relatively large number of aphids. This agrees with the observation in the field that some plants are able to make normal growth in spite of carrying a heavy infestation of aphids.

In McPherson, Lyon, and Shawnee counties, a heavy infestation occurred in cooperative alfalfa variety tests where Ladak was grown under comparable farm conditions with commonly grown varieties.

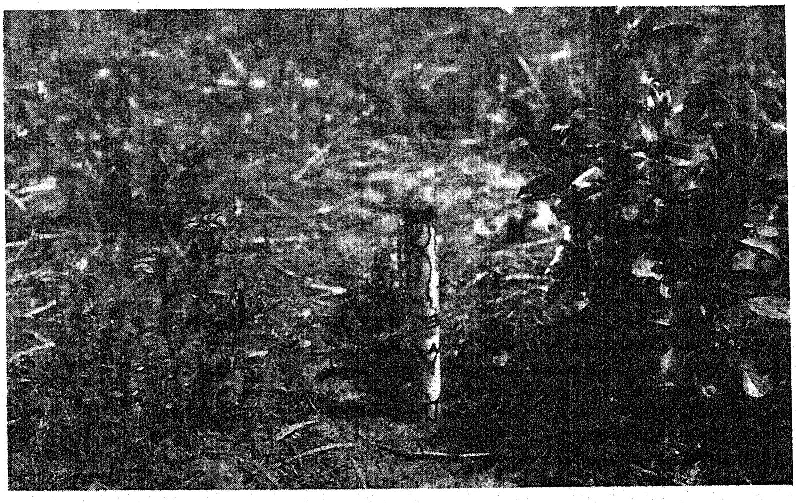

FIG. 1.—Plants resistant (right) and susceptible (left) to pea aphids growing in a field of Kansas common alfalfa.

In these tests, Ladak was infested and damaged in every case to a smaller extent than other varieties. In the tests in McPherson and Lyon counties, the infestation was very heavy, and the difference between Ladak and the other varieties was as great as at Manhattan. Ladak was injured from 0 to 10%, while Kansas common, Grimm, and several other sorts were injured 50 to 75%. In the Shawnee County test, the infestation and damage was not as great, but the results were similar so far as the varieties were the same.

In addition to these records, C. E. Crews, in charge of the south central Kansas experimental fields near Kingman and Wichita reported that Ladak appeared much less susceptible than other varieties under a moderate infestation of the pea aphids.

From a study of the nursery rows, consisting of almost 500 recent importations, it was evident from the estimate of pea aphid damage that the Turkestans as a group were injured less than other varieties. No other group of alfalfas originating from a single region showed as much resistance to pea aphid injury.

In the alfalfa breeding nursery there are selfed lines in the third generation. Here it was possible to compare the resistance of the original plant with that of selections in the third generation of self pollination. In one case it was found that the original plant and most lines from this plant were highly resistant to pea aphid injury. In all other lines it was evident that segregation was still going on. Studies are being conducted to learn more about the inheritance of pea aphid resistance.

GRAZING TIME OF BEEF STEERS ON PERMANENT PASTURES[1]

M. A. HEIN[2]

IN the course of a pasture experiment at Beltsville, Md., data were collected on the time animals spend in grazing. These permanent pastures were located on the Animal Husbandry Farm and were used in a cooperative pasture management experiment with beef cattle.

PROCEDURE

The method used was to keep a record of the time the animals actually spent in grazing during a continuous 24-hour period from 6 a. m. one day to 6 a. m. the following day. Records were taken every 15 minutes during this period. These data were collected for three 24-hour periods in 1931 and in 1932. In 1931 the animals were so marked that it was possible to obtain data on the individual animals without disturbing their normal habits, but in 1932 this was not possible and the records were taken as a group for each pasture.

Four pastures were located adjacent to each other and grazed with three lots of animals. Pasture A-1 (light continuous grazing) contained 8 acres grazed at the rate of one animal to 2 acres, A-2 (heavy continuous grazing) 5 acres with one animal per acre, while A-3 North and A-3 South (heavy alternate grazing) were 2 acres each with one animal per acre. The animals were long yearlings or short 2-year-old steers in thrifty condition and during the periods of collecting the data they were making an average daily gain from 0.75 to 2.00 pounds per head. In 1931, the pastures furnished an abundance of herbage, but in 1932 a shortage of rainfall in the summer limited the grass growth after July, especially on the heavily grazed pastures.

RESULTS

The records obtained in 1931 (Tables 1, 2, and 3) indicate that, in general, animals in the same pasture graze as a group, all spending about the same time in grazing. Steer No. 86 was an exception, but it was observed that he was of a more nervous temperament than the others. From the weight records obtained at 28-day intervals, the individual animals of similar temperament, grazing the shorter time, made slightly higher gains. The time spent in grazing, however, was influenced more by the comparative abundance of the pasturage than by the peculiarities of the individual animal. This is brought out when the average grazing time of lot 3 in 1931 is compared with lots 1 and 2 on the three different days. On September 20 and October 9, lot 3 spent on the average 2 hours more time per day grazing than did lots 1 or 2, while on October 2 all lots averaged about the same time. On October 2, lot 3 had just been moved to the other pasture which had not been grazed for two weeks

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and contained an abundance of forage, while on September 20 and October 9, lot 3 was on a pasture that was very closely grazed.

Similar results were obtained in 1932 (Table 4). On July 21, it will be noted that lot 3 averaged slightly over 2 hours more time in grazing than lots 1 and 2 and on this date the pasture was very closely grazed before removing the animals. The records of July 2 and August 23 were taken just after the animals had been moved to the pasture, which had had an opportunity to recover and again the time of grazing was about equal for all three lots.

TABLE 1.—*Grazing time of individual steers in a 24-hour period, September 20, 1931.*

Lot 1, Light Continuous Grazing

	Steer No.								Average	
	77		84		90		91			
	Hr.	Min.	Hr.	Min.	Hr.	Min.	Hr.	Min.	Hr.	Min.
6 a.m. to 6 p.m.	5	15	5	15	5	0	5	15	5	11
6 p.m. to 6 a.m.	3	15	3	45	3	45	3	45	3	38
Total....	8	30	9	0	8	45	9	0	8	49

Lot 2, Heavy Continuous Grazing

	Steer No.										Average	
	80		81		83		86		87			
	Hr.	Min.	Hr.	Min.	Hr.	Min.	Hr.	Min.	Hr.	Min.	Hr.	Min.
6 a.m. to 6 p.m.	5	15	5	15	5	15	5	30	5	15	5	18
6 p.m. to 6 a.m.	3	45	3	30	2	45	4	15	2	0	3	15
Total....	9	0	8	45	8	0	9	45	7	15	8	33

Lot 3, Heavy Alternate Grazing

	Steer No.								Average	
	73		79		82		85			
	Hr.	Min.	Hr.	Min.	Hr.	Min.	Hr.	Min.	Hr.	Min.
6 a.m. to 6 p.m.	5	0	5	0	5	0	5	0	5	0
6 p.m. to 6 a.m.	5	0	5	15	5	15	6	15	5	26
Total....	10	0	10	15	10	15	11	15	10	26

Temperature: Maximum 96° F; minimum 67° F. Sunrise 5:55 a.m.; sunset 6:07 p.m.

The differences are not so pronounced between the continuously light and heavygrazed pastures for the reason that the herbage supply was not reduced as rapidly on the continuously heavy grazed pasture as on the alternately heavy grazed pasture, where the same number of animals were confined to a smaller area. In 1932, when the herbage was less abundant, the animals on the continuously heavy grazed pasture averaged 31 minutes more time per 24-hour period in grazing than did the animals on the continuously light grazed pastures.

TABLE 2.—*Grazing time of individual steers in a 24-hour period October 2, 1931.*

Lot 1, Light Continuous Grazing

	Steer No.								Average	
	77		84		90		91			
	Hr.	Min.	Hr.	Min.	Hr.	Min.	Hr.	Min.	Hr.	Min.
6 a.m. to 6 p.m.	6	30	7	0	7	45	6	15	6	53
6 p.m. to 6 a.m.	3	15	3	0	2	15	2	15	2	41
Total....	9	45	10	0	10	0	8	30	9	34

Lot 2, Heavy Continuous Grazing

	Steer No.										Average	
	80		81		83		86		87			
	Hr.	Min.	Hr.	Min.	Hr.	Min.	Hr.	Min.	Hr.	Min.	Hr.	Min.
6 a.m. to 6 p.m.	5	0	5	45	5	45	6	45	5	45	5	48
6 p.m. to 6 a.m.	3	0	2	45	2	30	2	30	3	0	2	45
Total....	8	0	8	30	8	15	9	15	8	45	8	33

Lot 3, Heavy Alternate Grazing

	Steer No.								Average	
	73		79		82		85			
	Hr.	Min.	Hr.	Min.	Hr.	Min.	Hr.	Min.	Hr.	Min.
6 a.m. to 6 p.m.	6	15	6	15	6	15	5	45	6	8
6 p.m. to 6 a.m.	2	15	2	15	2	30	3	0	2	30
Total....	8	30	8	30	8	45	8	45	8	38

Temperature: Maximum 86° F; minimum 52° F. Sunrise 6:06 a.m.; sunset 5:48 p.m.

Comparing the 1931 and 1932 results, it will be noted that on the average, the animals spent more time in grazing in 1932 than in 1931, which can be accounted for in the less abundant herbage in the pastures in 1932 due to lack of rainfall.

TABLE 3.—*Grazing time of individual steers in a 24-hour period, October 9, 1931.*

Lot 1, Light Continuous Grazing

	Steer No.								Average	
	77		84		90		91			
	Hr.	Min.	Hr.	Min.	Hr.	Min.	Hr.	Min.	Hr.	Min.
6 a.m. to 6 p.m.	5	15	5	0	7	30	4	45	5	38
6 p.m. to 6 a.m.	1	30	3	0	1	45	2	45	2	15
Total....	6	45	8	0	9	15	7	30	7	53

Lot 2, Heavy Continuous Grazing

	Steer No.										Average	
	80		81		83		86		87			
	Hr.	Min.	Hr.	Min.	Hr.	Min.	Hr.	Min.	Hr.	Min.	Hr.	Min.
6 a.m. to 6 p.m.	6	45	7	30	6	30	8	45	6	30	7	12
6 p.m. to 6 a.m.	2	45	2	30	1	45	1	15	1	15	1	54
Total....	9	30	10	0	8	15	10	0	7	45	9	6

Lot 3, Heavy Alternate Grazing

	Steer No.								Average	
	73		79		82		85			
	Hr.	Min.	Hr.	Min.	Hr.	Min.	Hr.	Min.	Hr.	Min.
6 a.m. to 6 p.m.	8	30	9	0	9	0	9	30	9	0
6 p.m. to 6 a. m.	1	30	2	15	1	30	2	15	1	53
Total	10	0	11	15	10	30	11	45	10	53

Temperature: Maximum 70° F; minimum 38° F. Sunrise 6:13 a.m.; sunset 5:37 p.m.

In the course of the two years some rather interesting observations were made on the grazing activities which are not apparent from the data recorded. The animals did not graze at night expect when it was moonlight or when the visibility was good, as in the twilight. If a fog came up they "bedded down" in a very short time. They grazed more intensively between 5 p. m. and 8 p. m. and between 5 a. m. and 8 a. m. than at any other period during the 24 hours.

On hot days grazing began somewhat earlier in the morning and, after the mid-day rest, was resumed later in the evening, while if the day was cool a little more time was spent in grazing during mid-day. In general, however, it seemed that there were two rather definite grazing periods in each 24 hours.

In a more detailed study of the various activities of grazing animals in North Dakota[3] and Texas,[4] similar observations on the grazing habits of livestock were made. In North Dakota beef steers on sweet clover pasture spent 8¼ hours in grazing, while in Texas cattle on range pasture spent about 7¾ hours during a 24-hour period. The results obtained in Texas are an average of 36 observations made during the period from January 1924 to December 1926.

TABLE 4.—*Grazing time in 24-hour period on three different dates in 1932.*

	July 2*		July 21†		August 23‡		Average	
	Hr.	Min.	Hr.	Min.	Hr.	Min.	Hr.	Min.
Continuous Light Grazing								
6 a.m. to 6 p.m.......	4	50	5	10	7	15	5	45
6 p.m. to 6 a.m.......	5	5	3	45	3	20	4	3
Total............	9	55	8	55	10	35	9	48
Continuous Heavy Grazing								
6 a.m. to 6 p. m......	5	8	5	0	8	4	6	4
6 p.m. to 6 a.m......	5	12	4	44	2	48	4	15
Total............	10	20	9	44	10	52	10	19
Heavy Alternate Grazing								
6 a.m. to 6 p.m......	4	30	7	25	7	15	6	23
6 p.m. to 6 a.m......	4	50	4	0	2	55	3	55
Total............	9	20	11	25	10	10	10	18

*Night clear, no moon, N. W. wind. Poor visibility between 8:45 p.m. and 3:30 a.m. Cold for this season of the year. Maximum 81°, minimum 58°.

†Cloudy, visibility better than on July 2. High humidity, three showers during the day; hot and muggy. Maximum 90°, minimum 67°.

‡Cool, cloudy night; moon rose at 11:30 p.m. Heavy fog from 2 a.m. to 5:30 a.m. Hot day, no clouds. Maximum 88°, minimum 51°.

SUMMARY AND CONCLUSIONS

The factor that affected the total time spent in grazing during a 24-hour period was the amount of feed present.

When the pastures furnished an abundance of forage, approximately 8¾ hours of a 24-hour period were spent in grazing. When herbage was not so plentiful, approximately 10 hours were spent in grazing.

Approximately 66% of the grazing occurred during the daylight period from 6 a. m. to 6 p. m.

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[3] SHEPPERD, J. H. Sweet clover experiments in pasturing. N. D. Agr. Exp. Sta. Bul. 211. 1927.

[4] CORY, V. L. Activities of livestock on the range. Tex. Agr. Exp. Sta. Bul. 367. 1927.

NOTES

THE ADAPTATION OF CORN TO CLIMATE

THE article on "The Adaptation of Corn to Climate" which appeared recently in this JOURNAL (Vol. 27, pages 261 to 270), is interesting and stimulating. Agronomists may well maintain open minds regarding the factors involved in the ecological relations of crop plants. However, the value of correlating individual facts to develop working hypotheses must depend largely on whether the data used are typical for the problem awaiting solution. The validity of an ecological theory may be tested by its success or failure in explaining responses to the same factors elsewhere.

Extensive variety testing of standard corn varieties at New Brunswick, New Jersey, for a 3-year period, has indicated that varieties introduced into that state from other corn-growing states to the north, south, and west were almost invariably inferior to well-adapted local strains. The average yield of 61 standard varieties from 14 other states was 19.2% less than that of adapted strains, when the value of both grain and stover was included. In grain yield alone, the introduced varieties averaged 27.8% less than that of adapted strains. Only two of the introduced varieties equaled the yield of adapted varieties, and none exceeded the best local strains. Certain of the so-called silage varieties produced more dry matter per acre than the better local strains, but they yielded considerably less actual feed per acre because of the greatly inferior ear development of the southern varieties.

It was found in cooperative tests with farmers that many local strains were poorly adapted, either because of the recent introduction of seed from other states or because of seed selection methods which ran contrary to natural selection of adapted types. The detailed results of these tests are presented in New Jersey Agricultural Experiment Station Bulletin 537. Although the number of varieties tested yearly since 1930 has been reduced, the later results have substantiated the earlier findings.

Since New Jersey is not greatly separated from Connecticut in distance, nor markedly different in climate and soil, the results of variety testing in the two states should show similar trends. The trials of corn varieties in New Jersey do not support the general rule proposed by Jones and Huntington which states that, "Corn may be moved from a less favorable to a more favorable climatic region without loss of productive capacity, and usually with distinct gain." On the contrary, the figures in Table 1 from the New Jersey experiments support the principle that varieties grown and properly selected in a given environment normally exhibit greater adaptation to that particular complex of conditions than varieties introduced from a region with different conditions of soil, climate, and pests.

In making comparisons with introduced varieties, a great deal depends on the particular local strains used as the standard. In a state where comparatively little attention has been given to selection of adapted strains, many of those grown by farmers are low

TABLE 1.—*Yields of standard varieties of corn when grown at New Brunswick, N. J., 1928–30, inclusive.*

Variety	Source	Cured stover per acre, lbs.	Shelled grain per acre, bu.
Reid's Yellow Dent..........	New Jersey	9,083	62.2
Reid's Yellow Dent..........	Illinois	9,411	51.3
Reid's Yellow Dent..........	Indiana	10,189	43.1
Reid's Yellow Dent..........	Iowa	6,822	49.0
Reid's Yellow Dent..........	Kansas	9,502	47.1
Reid's Yellow Dent..........	Nebraska	7,021	48.7
Lancaster Surecrop..........	New Jersey	9,126	55.5
Lancaster Surecrop..........	Pennsylvania	7,634	48.1
Eureka Ensilage.............	Virginia	12,532	33.2
Cocke's Prolific.............	Virginia	9,765	33.8
Cocke's Prolific.............	Mississippi	9,853	41.5

in productivity. In all fairness, comparisons should be made between varieties that are well suited to the localities in which they originate.

TABLE 2.—*Variability of local strains in New Jersey.*

Variety	Cured stover per acre, lbs.	Shelled grain per acre, bu.
Tests Conducted in South Jersey, 1928–31, Inc.		
Hulsart Yellow Dent.......................	3,915	32.7
Local Yellow—A..........................	3,445	26.4
Local Yellow—B..........................	4,406	21.9
Local Yellow—C..........................	4,083	19.5
Tests Conducted in North Jersey, 1928–31, Inc.		
Mercer White Cap.........................	5,587	55.1
Local White Cap—A.......................	6,037	51.0
Local White Cap—B.......................	3,909	42.8
Local Yellow—C..........................	3,734	41.9

The named varieties in Table 2 are also local strains, but they have been produced by growers who consistently practice desirable methods of selection. The other varieties had either been introduced from other states within a 3- or 4-year period prior to testing, or had been selected for characters known to be antagonistic to high yields, such as excessive kernel depth and roughness, large diameter of ear, and very tall stalks.

Before adopting the principles laid down by Jones and Huntington, it would be desirable to determine the degree to which these principles explain the results of variety trials throughout the corn-growing region. The results of adaptation tests with corn varieties in such states as Kansas and Nebraska apparently do not harmonize with these principles. For satisfactory application to New Jersey, some important changes in concept certainly seem necessary.—H. B. SPRAGUE, *New Jersey Agricultural Experiment Station, New Brunswick, N. J.*

FURTHER COMMENTS ON ADAPTATION OF CORN TO CLIMATE

DARWIN once said that "the thing that disgusted him most was that two people could take the same facts and arrive at opposite conclusions." This seems to have happened to Sprague and ourselves. He doubts our thesis that "corn may be moved from a less favorable to a more favorable climatic region without loss of productive capacity, and usually with distinct gain, provided the length of the growing season permits satisfactory maturity." We think that his original data in Bulletin 537 of the New Jersey Agricultural Experiment Station support this thesis, or at least do not contradict it. From among the 14 New Jersey varieties which were tested by Sprague and his co-workers, they selected the 6 with the highest yield and compared them with 61 varieties which they had brought in from 14 other states. This is an unfair comparison in several ways. In the first place, four of the six selected New Jersey varieties originated outside that state, and one of the others appears to be a western variety grown locally and renamed, even though all had been selected in New Jersey long enough to be well adapted to local conditions.

In the second place, although the best six New Jersey varieties were chosen, no corresponding selection was made among the 61 varieties from other states, and some varieties known to be of low yield have been used. A third reason for questioning Sprague's use of his data is that portions of the 14 states from which seed was brought to New Jersey, for example Pennsylvania and the parts of the states from Ohio to Iowa from which the seed was presumably obtained, are climatically about on a par with northern New Jersey or even better. Hence, according to our theory, the yield from such states would remain about the same when seed was brought to New Jersey. The facts bear this out, for according to New Jersey Bulletin 537, the average yield of all varieties of corn raised in New Jersey from Illinois seed was 52.9 bushels, from Ohio seed 51.7 bushels, and from New Jersey seed 50.8 bushels. If we select only the highest yielding varieties, the Illinois seed is again first with 66.4 bushels as compared with 62.2 bushels for New Jersey. Two hybrid varieties from Iowa yielded 69.0 and 62.9 bushels, respectively, but part of this high yield may have been due to hybrid vigor. Other western and more southern seed failed to yield as much as New Jersey varieties by a considerable margin.

Turning now to the value of corn as forage, in New Jersey Bulletin 537, 4.5 pounds of stover is taken as being equal to 1 pound of grain in feeding value, and on this basis the relative amounts of feed produced by different varieties are calculated. Taking the averages of all varieties and classifying the results according to where the seed was obtained, the order is as follows: Kansas, 95.1; Illinois, 94.4; Ohio, 88.7; and New Jersey, 87.8. It is rather surprising that the seed from southern Pennsylvania and from states farther south does not make so good a showing. If determinations of total dry matter were made, varieties from these sources would probably stand relatively higher as they do in Connecticut. It should be noted in this connection that the difference in yield of corn between the central corn-growing states and New Jersey is much less than between those same states and Connecticut.

Sprague's second table seems to us irrelevant to the specific point at issue, although it is interesting and valuable from other viewpoints. The superiority of some varieties points to a conclusion which we would be the last to question, namely, that corn can be improved by proper selection. The great contrast between the yields in northern New Jersey—42 to 55 bushels per acre—and in southern New Jersey—20 to 33 bushels—points to another conclusion on which we insist strongly, *viz.*, that corn responds with peculiar readiness to variations in climate. The data on which our article was based show that a rise of only a very few degrees above the optimum temperature greatly reduces the yield of corn. Northern New Jersey is about 2 degrees too warm for the best results and southern New Jersey about 4 degrees. This seems like very little, and of course, differences in soil and so forth must be taken into account. Nevertheless, in the critical periods in the development of a corn plant, a very small rise in temperature does great damage. Some of the highest yielding New Jersey varieties used in Sprague's comparisons were moved from the southern to the northern part of the state, and this change is probably greater climatically than the change from some of the western states of the same or more northerly latitude into New Jersey.

None of the figures that Sprague has brought forth as well as those which we have extracted from New Jersey Bulletin 537 have any critical bearing on the point at issue, which is, Do varieties of corn perform as well as in their place of origin or even increase in yield when changed from a less favorable to a more favorable climatic region? To answer this question we must know also the yields of the varieties in their native environment.

Part of our own data are also inconclusive in that they do not show the yields of the introduced varieties in their native environment. More information of this nature is needed. Seasonal conditions vary widely in different places so that yields would have to be based on long-time averages. The results from sweet corn are somewhat more dependable, since with this material, varieties have been moved in both directions with results that are consistent with our conclusions. Take, for example, Golden Cross Bantam which originated in Indiana. As a general rule the plants grow taller and produce larger ears in Connecticut and in Massachusetts than they do in the central states. On the other hand, Redgreen, a Connecticut product, that is used for canning in central New York and yields abundantly there, has rarely produced a satisfactory crop in any of the midwestern states but has produced more marketable ears per acre in cool areas, such as Nevada, Idaho, and Washington, than in Connecticut.—DONALD F. JONES and ELLSWORTH HUNTINGTON, *Connecticut Agricultural Experiment Station, New Haven, Conn.*

AGRONOMIC AFFAIRS

A TRIBUTE TO DOCTOR LIPMAN

THE advisory staff of Soil Science has dedicated Volume 40 of that journal, and particularly the first number of the volume, to Dr. J. G. Lipman, founder and Editor-in-Chief for twenty years, in honor of his editorship and his long-continued service to soil science and agriculture. Dr. Lipman is on sabbatic leave this year, thus affording the editorial staff an excellent opportunity to honor their chief.

Among the special features appearing in the July number of Soil Science are the following: A brief biographical sketch of Dr. Lipman; "Jacob G. Lipman and Soil Science," by E. J. Russell; "Jacob G. Lipman as an Investigator," by Selman A. Waksman; "Jacob G. Lipman and New Jersey Agriculture," by A. W. Blair; and "Jacob G. Lipman as Teacher and Director of Research," by Robert V. Allison.

MEETING OF WESTERN SECTION OF SOCIETY

THE nineteenth annual meeting of the Western Section of the Society met at Pendleton, Ore., June 18 to 20, with 62 agronomists in attendance, representing seven states and the U. S. Dept. of Agriculture. A total of 28 papers was presented at five sessions, with one afternoon devoted to a tour of inspection of the Pendleton field station and the Wildhorse soil erosion project. Details regarding the papers presented on the formal program may be obtained from the Secretary of the Section.

At the business meeting it was voted to hold the 1936 meeting jointly at the Washington State College, Pullman, Wash., and the University of Idaho, Moscow, Idaho. Dr. R. S. Hawkins of the University of Arizona was elected President of the Section, succeeding Prof. B. A. Madson of the University of California; and Prof. E. G. Schafer of Washington State College was named Secretary, succeeding J. Foster Martin of Pendleton, Ore.

NEWS ITEMS

Robert E. Fore has been awarded the degree of Doctor of Philosophy by the University of Illinois, the major subject of his graduate studies being in plant breeding.

It was voted at the recent meeting of the Corn Belt Section of the Society at St. Paul, Minn., to hold the next annual meeting of the Section at the University of Illinois.

Word has been received of the death of Mr. S. H. Essary, Botanist at the Tennessee Agricultural Experiment Station and for many years a member of the Society.

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A SEARCH FOR FACTORS DETERMINING WINTER HARDINESS IN ALFALFA[1]

C. R. MEGEE[2]

IN the northern part of the United States winter killing of alfalfa is often prevalent and the seeding of winter hardy strains is of paramount importance in maintaining satisfactory stands. Field tests to determine the relative winter hardiness of the various strains of alfalfa have contributed much toward enabling Michigan to become the second highest state in the acreage of alfalfa in the United States. The hardy strains of alfalfa, such as Hardigan and Grimm, are usually able to withstand low temperatures without winter killing, while the non-hardy strains, such as Arizona Common and Hairy Peruvian, often are killed the first winter. There are many strains occupying an intermediate position of winter hardiness between these extremes.

During the past 15 years the writer (14)[3] has conducted many field tests to determine the relative winter hardiness of the various strains of alfalfa of the United States and many foreign countries. In order for a field test to reach a high degree of dependability it is necessary that it extend over a period of from 4 to 8 years and this involves a serious delay as well as considerable expense in conducting the test. While such tests have been of much value in determining the relative winter hardiness of the various strains of alfalfa, they have in no way explained the phenomenon of winter hardiness.

Increase in colloid content and osmotic pressure of root sap and decrease in moisture content of alfalfa tissue have been suggested as an explanation for winter hardiness. Should it be possible to locate some one or more factors definitely correlated with winter hardiness that could readily be determined in the laboratory, this problem of the agronomist would be greatly simplified.

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[1] Contribution from the Soils Section, Michigan State College, East Lansing, Mich. Taken from a thesis submitted to the Faculty of Michigan State College in partial fulfillment of the requirement for the degree of doctor of philosophy. Published as journal article No. 220 n. s. of the Michigan Agricultural Experiment Station. Received for publication June 25, 1935.

[2] Associate Professor. The author expresses his appreciation to members of the Soils Department and to Prof. H. C. Rather and Dr. R. P. Hubbard of the Farm Crops and Botany Departments, respectively, for helpful suggestions during the progress of the experimental work and preparation of the manuscript.

[3] Figures in parenthesis refer to "Literature Cited," p. 698.

The object of this paper is to present data on the relationship between winter hardiness of alfalfa and various properties of alfalfa root tissue as measured by electrical conductivity, moisture equivalent, swelling, heat of wetting of oven-dry tissue, respiration, freezing point depression, moisture content, and the rate of loss of moisture. Should any of the above factors prove to be directly correlated with winter hardiness, the fact would be an important step in determining and possibly explaining the phenomenon of winter hardiness.

It is generally recognized that damage to plants may result from winter injury due to several causes, such as low temperature, heaving of soil and plants by the building up of layers of ice in the soil, suffocation under an ice crust, and the desiccation of plant tissues due to dry winds. In this paper only the first form, winter injury due to low temperature, is considered. In the experiments here reported, the other three forms of winter injury were almost, if not entirely, absent.

REVIEW OF LITERATURE

No attempt will be made to review the voluminous literature on the subject of winter hardiness. Harvey (12) gives a very complete bibliography on the low temperature relations of plants. Chandler (5), Dexter, *et al.* (6), Graber, *et al.* (10), Gortner (9), Harvey (11), Maximov (13), Newton (15), and Rosa (16) not only give their views but also have reviewed the work of other investigators. Dexter, *et al.* (6), upon mentioning the work of other investigators states: "It may be briefly stated that most, if not all, of the theories of winter hardiness are built around the idea of the water relation of the plants and that structural, osmotic, or colloidal protection from water withdrawal or ice formation form the basis of explanation for individual or varietal differences in hardiness."

MATERIAL USED

Three strains of alfalfa of known winter hardiness, Hardigan, Utah Common and Arizona Common, were selected for these experiments from among a large number of strains representing most of the seed-producing sections of the world. Field tests of these strains for winter hardiness were previously conducted by the writer over a period of 8 years. Plats seeded in 1921 were continued until 1929. Other plats seeded in 1922, 1923, and 1924 were continued for periods ranging from 3 to 5 years. Table 1 shows the comparative winter hardiness of these three strains under Michigan conditions.

TABLE 1.—*Comparative winter hardiness as indicated by yield of Hardigan, Utah Common, and Arizona Common alfalfas at East Lansing, Michigan.*

Variety	Yields of hay expressed in per cent of Hardigan yields									Average yield per acre, tons
	1922	1923	1924	1925	1926	1927	1928	1929	Average	
Hardigan...	100	100	100	100	100	100	100	100	100	4.8
Utah Common......	93.7	82.9	90.7	65.9	50.2	47.0	64.6	57.6	69.1	3.3
Arizona Common	63.3	10.8	19.6	11.7	21.9	0.0	0.0	0.0	15.9	0.8

Hardigan is a variegated strain of alfalfa developed at the Michigan Agricultural Experiment Station and is very winter hardy under Michigan conditions. Utah Common is a strain of only medium winter hardiness and has been grown for many years in the alfalfa seed-producing section of the Uinta Basin of Utah. Arizona Common is from the Yuma Valley of southwestern Arizona and is one of the least winter hardy strains of alfalfa.

It has been observed that alfalfa plants sometimes live through the winter entirely devoid of leaves. In view of this observation the material used in the laboratory tests consisted of the root and a portion of the crown, the top being removed just above the lower crown buds. Although containing a portion of the crown, this material is referred to as the root.

The roots used were of the first season's growth and were grown on a Hillsdale sandy loam soil. Roots were used from both fertilized and unfertilized plats. The amounts of superphosphate and muriate of potash necessary to apply to the soil in order to have a good supply of available phosphorus and potassium present as determined by the Spurway method (17) were found to be equivalent to the nutrients in an application of 2,400 pounds per acre of an 0–8–24 fertilizer. These materials were applied to a series of plats on May 29 and worked in as the soil was prepared for seeding which was done June 8. On September 4 a like application was made as a top dressing on another series of plats. On the same date an application of 500 pounds per acre of nitrate of soda as a top dressing was made on a third series of plats. The fertilized plats were 25 x 300 feet and the varieties of alfalfa were seeded in quadruplicate plats 25 x 330 feet running across the fertilized and unfertilized plats. This arrangement provided roots of both hardy and non-hardy alfalfas grown on fertilized and unfertilized soil.

EXPERIMENTAL RESULTS

RELATION BETWEEN WINTER HARDINESS AND LIBERATION OF ELECTROLYTES BY ALFALFA ROOT TISSUE EXPOSED TO LOW TEMPERATURE

It is a matter of frequent observation that as the living protoplasm of a cell is injured it becomes more permeable and the electrolytes pass out of the cell. As the injury becomes more intense the permeability increases and additional electrolytes are liberated. To determine the amount of electrolytes liberated when alfalfa roots were submitted to low temperature, electrical conductivity determinations were made on water extracts of roots of hardy and non-hardy alfalfas collected from fertilized and unfertilized plats. The method suggested by Dexter, *et al.* (6) was used.

Extreme care must be exercised in preparing alfalfa field material for electrical conductivity tests. Hardigan, though one of the most uniform strains of alfalfa, is not a pure line selection owing to its method of pollination. Consequently, some variations will be found in the winter hardiness of different individual plants. Also, an entirely uniform soil cannot be secured for field work. To eliminate these variations in so far as possible, plants were selected from various parts of the plat and after thorough washing and removal of the external moisture, the roots were cut into ¾ inch pieces and the pieces thoroughly mixed so that the 10-gram sample used would represent the plat as a whole.

The samples were then placed in Pyrex glass tubes and the tubes held in alcohol slush in a cold chamber. The alcohol slush was found to be very efficient in maintaining the material at a constant temperature, variations seldom exceeding 1°. Samples taken in October and November were frozen at —9° C for 4 hours, but as the season advanced it was found necessary to freeze later samplings for a longer period, or at a lower temperature. At the end of the freezing period 75 cc of distilled water were added and the tubes placed in a water bath maintained at 2° C. Exosmosis was allowed to proceed for 20 hours, at the end of which time conductivity readings were made by means of a Wheatstone bridge. The Wheatstone bridge readings are expressed in specific conductivity ($x\ 10^{-6}$) in reciprocal ohms (mhos) per gram of dry matter. Before making the reading each tube was inverted three times to secure an equal distribution of the electrolytes through the solution. Student's method was applied to data from triplicate samples and in most instances differences greater than 8% were found to be significant.

Electrical conductivity tests were made on samples of roots taken October 16, 1933, from the Hardigan and Arizona Common varieties from plats receiving no fertilizer treatment and from plats receiving each of the fertilizer treatments. No varietal or plat differences were found. Hardening had not developed to a point where a distinction could be made between hardy and non-hardy alfalfas.

On November 23, 1933, the test was repeated. The roots were frozen 4 hours at —9° C and 20 hours were allowed for exosmosis.

TABLE 2.—*Effect of freezing on the liberation of electrolytes from roots of hardy and non-hardy alfalfas grown on fertilized and unfertilized soil, test made November 23, 1933.*

Fertilizer treatment	Portion of root used	Mhos per gram of dry matter		Difference, %
		Hardigan	Arizona Common	
None........	Upper 5 inches	37.0	53.7	45.1
	Lower and fibrous	61.5	70.5	14.6
0-8-24.......	Upper 5 inches	50.5	64.5	27.7
Sept. 4	Lower and fibrous	75.1	77.5	3.1

The results, presented in Table 2, show that the Hardigan roots were much more resistant to low temperature than were those of Arizona Common. Resistance to damage from low temperature developed most rapidly in the upper portion of the tap root, while it was delayed at lower depths and in the small lateral and hair roots. Heavy applications of an 0-8-24 fertilizer on September 4 caused resistance to damage by cold to develop slowly. No difference was found in the average air-dried weight of hardy and non-hardy alfalfa roots, consequently the weight of the root is not a factor in winter hardiness.

In contrast to the results presented above, no differences were found in the winter hardiness of alfalfa roots from the plats receiving no fertilizer, the roots from plats receiving fertilizer on May 29, and the roots from plats receiving nitrate of soda on September 4.

The electrical conductivity tests were repeated on samples taken December 16 and December 18. The relationship of Hardigan to Arizona Common and the effects of different soil treatments had not changed. Somewhat more resistance to liberation of solubles through freezing had developed, but just how much could not be determined because the roots dug December 16 were frozen for 15 hours at —9° C and those dug December 18 were frozen for 6 hours at —15° C.

Another lot of Hardigan roots was dug January 15, the object of this test being to determine the relative winter hardiness of the roots from plats receiving no fertilizer treatment with those from plats receiving 2,400 pounds of 0–8–24 on September 4, and also to determine the relative amounts of electrolytes liberated when the roots were not cut, when cut into ¾ inch lengths and into ⅜ inch lengths, and when ground. The roots were frozen 15 hours at —9° C and 20 hours were allowed for exosmosis at 2° C. After the determinations were made the samples were boiled for 15 minutes, 20 hours allowed for exosmosis at 2° C, and the electrical conductivity redetermined.

TABLE 3.—*The effect of freezing upon the liberation of electrolytes from roots of hardy alfalfa when grown on fertilized and unfertilized soil and when tap and fibrous roots were cut at different lengths and when ground, test made January 15, 1934.*

Part of roots used	Size of pieces	Mhos per gram of dry matter				Difference, %	
		No soil treatment		Fertilized Sept. 4			
		Frozen	Frozen and boiled	Frozen	Frozen and boiled	Frozen	Boiled
Tap....	Uncut	25.2	121.3	30.5	125.0	21.0	3.0
Tap....	¾ in.	28.7	137.2	34.7	139.5	20.9	1.6
Tap....	⅜ in.	34.3	143.6	41.2	144.5	20.1	0.6
Tap....	Ground	52.8	151.5	60.5	153.2	14.5	1.7
Fibrous	¾ in.	49.0	151.6	54.7	155.2	11.1	2.3
Fibrous	Ground	63.4	156.2	68.6	158.0	8.2	1.1

The results given in Tables 2 and 3 show that the roots from plats receiving an 0–8–24 fertilizer on September 4 hardened less rapidly during November than the roots from the other plats, but during late December and January they hardened more rapidly. The injurious effect of low temperature upon alfalfa roots receiving fertilizer during September would depend largely upon whether the soil temperature was low during the fall or whether it was low during the winter. During 1933–34 the soil temperature was not low until after January 15 and all plats of Hardigan came through with very little, if any, injury. None of the Arizona plats had been injured to any appreciable extent prior to January 15, but winter killed 99% by spring. The test ran January 15 showed that all plats of alfalfa had made a considerable increase in winter hardiness since November 23. This increase was greater than is shown by comparing the figures in Tables 2 and 3, since the roots dug November 25 were frozen 4 hours at —9° C, while those dug January 15 were frozen 15 hours at —9° C and the latter liberated less electrolytes.

Data in Table 3 also show that grinding tap roots and grinding and cutting fibrous roots failed to bring out differences in winter hardiness by the electrical conductivity method to the extent that was brought out with uncut roots and with tap roots cut in lengths of ¾ inch and ⅜ inch. The results secured after boiling show that the greater liberation of electrolytes from the roots from plats receiving fertilizer on September 4 was due to less hardening and not to an excess of salt stored in the roots. The results secured when the tests were repeated during the season of 1934–35 were the same, except that the amount of electrolytes released after boiling was somewhat more variable, likely due to the extreme drought of the summer of 1934. This fact did not change the relationship of one variety to another or of one plat treatment to another in comparison with the results of 1933–34. The electrical conductivity test was found to be valuable in determining the relative winter hardiness of different alfalfas.

PARTIAL CHEMICAL ANALYSIS OF HARDY AND NON-HARDY ALFALFA ROOTS

A chemical analysis[4] of the roots was made to determine whether there was a relationship between winter hardiness and the chemical composition of the roots. The results of the chemical analysis are shown in Table 4.

The chemical analysis of the alfalfa roots afforded no positive indication concerning factors causing winter hardiness. There are, however, some consistent differences in the protein and crude fiber content of the Hardigan and Arizona Common roots. On December 20, the date when a certain degree of winter hardiness had developed, the protein content of the Hardigan roots was higher than that of the Arizona Common roots and the increase in protein content at this date over that of October 16 was greater in the case of Hardigan than for Arizona Common. The crude fiber content of the Hardigan alfalfa was lower in all cases than that of the Arizona Common at both dates of sampling and the crude fiber content of Arizona Common increased markedly over that of Hardigan between the two dates. The sum of the protein and nitrogen-free extract content of Hardigan was slightly but consistently greater than that of Arizona Common.

MOISTURE CONTENT OF ROOTS OF HARDY AND NON-HARDY ALFALFAS

The moisture content of many winter hardy plants decreases as the fall and winter seasons advance. In order to determine the relationship between winter hardiness and moisture content, the amount of moisture in the roots of Hardigan and Arizona Common strains of al-

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[4] The writer hereby acknowledges the assistance of the Chemistry Section of the Michigan Agricultural Experiment Station in determining the chemical analysis.

TABLE 4.—*A comparison of partial chemical analysis of roots of hardy and non-hardy alfalfas.*

Variety	Treatment	H_2O %	Protein %	Ash %	Fat %	Crude fiber %	Nitrogen-free extract %	CHO %
Roots Dug October 16, 1934								
Hardigan	None	7.39	15.60	2.11	0.66	16.68	57.56	74.24
Arizona Com.	None	7.26	14.99	2.61	0.77	18.04	56.33	74.37
Hardigan	0–8–24, May 29	7.15	14.57	3.32	0.63	14.34	59.99	74.35
Arizona Com.		7.22	14.63	2.04	0.48	17.02	58.69	75.71
Hardigan	0–8–24, Sept. 4	7.22	15.16	2.63	0.69	14.60	59.70	74.30
Arizona Com.		7.04	14.29	2.80	0.39	17.33	58.15	75.48
Average		—	14.87	2.58	0.60	16.33	58.40	74.74
Roots Dug December 20, 1934								
Hardigan	None	5.27	19.08	2.23	1.76	23.39	48.27	71.66
Utah Com.	None	6.56	17.71	2.25	1.59	21.19	50.70	71.89
Arizona Com.	None	5.92	16.34	2.17	1.47	25.68	48.42	74.10
Hardigan	0–8–24, May 29	5.63	17.81	2.87	1.32	18.30	54.57	72.37
Utah Com.		5.98	17.50	2.53	0.97	19.02	53.65	72.67
Arizona Com.		6.03	15.71	2.63	1.32	21.25	53.41	74.66
Hardigan	0–8–24, Sept. 4	5.46	17.98	3.16	1.99	19.74	51.67	71.41
Arizona Com.		5.76	16.41	2.85	1.28	23.84	49.86	73.70
Average		—	17.31	2.59	1.46	21.55	51.32	72.80

falfa was determined at intervals during the fall and winter months. An electrically controlled oven maintained at 90° C was used for this purpose. The results are presented in Table 5.

TABLE 5.—*The moisture content of the roots of hardy and non-hardy alfalfas from October to February.*

Date roots were dug, 1934–35	Moisture %	
	Hardigan	Arizona Common
October 24	66.7	67.0
Nov. 19	60.0	61.3
Dec. 22	62.9	63.0
Jan. 1	62.4	62.3
Jan. 21	64.0	64.0
Feb. 6	68.4	68.5
Feb. 20	68.2	66.7
Growing	76.4	76.8
Average	66.1	66.2

The results show that no varietal differences in moisture content of the roots existed either during the fall or the winter months nor when the roots were in a growing condition. Hardened roots of winter hardy strains of alfalfa were low in moisture, as were the roots of the non-hardy alfalfas. Consequently, there is no significant correlation between winter hardiness and moisture content.

RATE OF LOSS OF MOISTURE FROM ROOTS OF HARDY AND NON-HARDY ALFALFAS

Protection against water withdrawal has been advanced as of importance in preventing winter injury. In case this is true Hardigan should release its moisture more slowly at low temperatures than would the less winter hardy Arizona Common. The relative loss of moisture of the roots of both Hardigan and Arizona Common was determined. Hardened living roots were dug February 20 and slowly reduced in moisture content in desiccators held at 2° C and at —9° C. The samples were weighed daily and the daily loss of moisture calculated. The results are shown in Table 6.

TABLE 6.—*The rate of loss of moisture from roots of hardy and non-hardy alfalfas held at 2° C and —9° C.*

No. days	Held at 2° C				Held at —9° C			
	Total loss %		Loss per day %		Total loss %		Loss per day %	
	Hardigan	Arizona Com.	Hardigan	Arizona Com.	Hardigan	Arizona Com.	Hardigan	Arizona Com.
1.....	23.0	21.0	23.0	21.0	14.0	18.2	14.0	18.2
2.....	33.8	32.4	10.8	11.4	25.6	27.0	11.6	8.8
3.....	48.2	45.8	14.4	13.4	35.6	38.8	10.0	11.8
4.....	59.0	57.4	10.8	11.6	43.8	48.0	8.2	9.2
5.....	62.4	62.6	3.4	5.2	47.6	52.4	3.8	4.4
6.....	64.0	65.4	1.6	2.8	48.6	53.4	1.0	1.0
7.....	64.8	66.2	0.8	0.8	60.0	62.4	11.4	9.0
8.....	65.0	66.4	0.2	0.2	63.0	63.8	3.0	1.4
9.....	65.4	66.8	0.4	0.4	65.0	64.6	2.0	0.8
10.....	65.6	66.8	0.2	0.0	66.8	65.2	1.8	0.6
11.....	66.0	67.4	0.4	0.6	67.4	66.0	0.6	0.8
12.....	68.2	69.2	2.2	1.8	68.6	66.0	1.2	0.0

On the eighth day samples of roots of both Hardigan and Arizona Common were removed from the desiccator held at 2° C. The roots were transplanted into flower pots filled with sandy soil and held at favorable conditions for growth. Growth was resumed, although 65% of the original weight of the roots had been lost due to the loss of moisture. The results show that both hardy and non-hardy alfalfa roots can withstand a heavy loss of moisture without being severely injured. The results also show that there is no consistent difference between hardy and non-hardy alfalfas in either the rate of loss of moisture or total moisture lost, and that the loss of moisture was not correlated with winter hardiness.

RELATIVE RATE OF RESPIRATION OF ROOTS OF HARDY AND NON-HARDY ALFALFAS

Respiration is the process of energy release in the living cell. The end products of aerobic respiration are CO_2 and water and the intensity of respiration may be determined by measuring the amount of CO_2 liberated over a given period of time. Plants become dormant as the fall and winter seasons advance and the process of energy release slows down.

In order to determine the relationship between winter hardiness and the rate of energy release, the relative rate of respiration of hardy and non-hardy alfalfas was determined. The roots were placed in 500-cc Erlemeyer flasks fitted with rubber stoppers and in-take and out-let tubes. The tubes were kept stoppered except when connected to the train for CO_2 determinations. The train was set up as follows: Air pump, potassium hydroxide solution, ascarite, phosphoric anhydride, concentrated sulfuric acid, sample, distilled water, and potassium hydroxide. Duplicate 20-gram samples were used. The apparatus was checked repeatedly for leaks. Each sample was connected into the train for 5 minutes, a previous test having shown that the air was completely changed in 2 minutes. The results are shown in Table 7.

TABLE 7.—*The relative rate of respiration of hardy and non-hardy alfalfa roots held at different temperatures.*

Condition of roots	Temperature, °C	Average daily liberation of CO_2, grams	
		Hardigan	Arizona Common
Not hardened	21°	0.1151	0.1185
Not hardened	10°	0.0163	0.0157
Not hardened	2°	0.0139	0.0129
Hardened	15°	0.0400	0.0384
Hardened	2°	0.0145	0.0140

The results show no difference in the rate of respiration between roots of hardy and non-hardy alfalfas.

RELATION BETWEEN WINTER HARDINESS AND PHYSICO-CHEMICAL BEHAVIOR OF COLLOIDAL MATERIAL IN ALFALFA ROOTS

The great importance of colloidal materials in the functioning of living matter immediately raises the question of the relationship between winter hardiness and the physico-chemical nature of the colloidal material in hardy and non-hardy alfalfas. Moisture equivalent (3), swelling (4), and heat of wetting (2) afford good indices of physico-chemical differences of colloidal materials. The above-mentioned indices were used to study the relationship between winter hardiness and the nature of the colloidal materials present in hardy and non-hardy alfalfas.

Roots of the hardy and non-hardy alfalfas from plats receiving the various fertilizer treatments were dug at dates ranging from October 21 to December 17. These roots were thoroughly washed, dried at air temperature, and ground to a very fine meal. Each sample was thoroughly mixed to facilitate sampling.

The moisture equivalent of colloidal material of the roots of hardy and non-hardy alfalfas.—The moisture equivalent was determined as follows: A Büchner funnel fitted with a filter paper was filled with ground roots and the funnel tapped gently 20 times to secure a uniform settling of the material. The funnel was then placed in a beaker of water for 4 hours and the excess water removed by means of suction filtration for 15 minutes. The material was then removed from the filter, weighed, and placed in an electrically controlled oven held at 90° C for 16 hours. The material was then weighed and the amount of water adsorbed was calculated. The results are presented in Table 8.

TABLE 8.—*The moisture equivalent of the colloidal material in roots of hardy and non-hardy alfalfas.*

Date roots were dug, 1934	Fertilizer treatment		Moisture equivalent %		
	Kind	Date applied, 1934	Hardigan	Utah Common	Arizona Common
Oct. 21	0-8-24	May 29	182	—	172
Nov. 6	None	—	200	—	199
Nov. 6	0-8-24	May 29	187	—	180
Nov. 6	0-8-24	Sept. 4	201	—	194
Nov. 6	Nitrate of soda	Sept. 4	207	—	198
Nov. 24	None	—	219	—	222
Nov. 24	0-8-24	May 29	221	—	215
Dec. 17	None	—	263	261	265
Dec. 17	0-8-24	May 29	266	262	252
Dec. 17	0-8-24	Sept. 4	256	264	269
Dec. 17	Nitrate of soda	Sept. 4	260	265	259

The results show a marked change from late October into December in the nature of the colloidal material present in the roots of both hardy and non-hardy alfalfas. Winter hardiness is not correlated with this change in the nature of the colloidal material since the change takes place to the same extent in both hardy and non-hardy alfalfas.

The swelling of colloidal material in the roots of hardy and non-hardy alfalfas.—A 5-gram sample of material was weighed out and placed in a 50-cc graduated cylinder which was then filled with distilled water to the 50 cc mark. The material was stirred to secure uniform wetting, shaken, and enough water added to fill again to the 50 cc mark. Care was exercised in securing cylinders of the same diameter and calibration. The cylinders were then placed in a chamber maintained at 10° C for 16 hours, at the end of which time reading was made. The results are shown in Table 9.

The results show a change from October 21 to December 17 in the physico-chemical nature of the colloidal material present in the roots. This change is shown by the increase in the swelling of the colloidal material. The seasonal change from October 21 to December 17 was the same for the non-hardy as for the hardy alfalfas. Fertilizer treatments did not influence the change. These results support those secured by the moisture equivalent index, in that winter hardiness is not a direct result of certain physico-chemical changes in the colloidal material of the alfalfa roots.

The heat of wetting of colloidal material in the roots of hardy and non-hardy alfalfas.—A 20-gram sample of air-dried material was placed in a wide glass tube and allowed to dry in an electrically heated oven at a temperature of 90° C for 16 hours. The tube was then removed from the oven, closed tightly with a rubber stopper, and placed on the desk close to the calorimeter, a liter of distilled water, and another sample of material, so that all samples and equip-

TABLE 9.—*The swelling of the colloidal material of the roots of hardy and non-hardy alfalfas during the fall and early winter months.*

Date roots were dug, 1934	Fertilizer treatment		Swelling in cc		
	Kind	Date applied, 1934	Hardigan	Utah Common	Arizona Common
Oct. 21	0–8–24	Sept. 4	24.0	—	24.5
Nov. 6	None	———	27.0	—	26.5
Nov. 6	0–8–24	May 29	26.5	—	27.0
Nov. 6	0–8–24	Sept. 4	27.0	—	27.0
Nov. 6	Nitrate of soda	Sept. 4	27.5	—	26.0
Nov. 24	None	———	33.5	—	33.0
Nov. 24	0–8–24	May 29	33.0	—	31.0
Dec. 17	None	———	34.0	34.0	34.0
Dec. 17	0–8–24	May 29	33.5	34.0	33.0
Dec. 17	0–8–24	Sept. 4	35.0	36.0	35.0
Dec. 17	Nitrate of soda	Sept. 4	34.0	33.0	35.0
Average of roots dug Dec. 17			34.1	34.2	34.2

ment would reach the same temperature. After a uniform temperature was established, 100 cc of water were placed in the calorimeter and the heat of wetting of the plant material ascertained (2). The tube was handled with a heavy cloth so that heat would not be imparted to the material. Great care was taken to have the calorimeter, the water, and the material at the same temperature, which was that of the room. The results are given in Table 10.

TABLE 10.—*The heat of wetting of colloidal material in the roots of hardy and non-hardy alfalfas.*

Date roots were dug, 1934	Fertilizer treatment		Heat of wetting, calories	
	Kind	Date applied, 1934	Hardigan	Arizona Common
Nov. 1	None	———	100.0	101.8
Nov. 1	0–8–24½	May 29	103.0	100.0
Dec. 17	None	———	131.0	131.2
Dec. 17	0–8–24	May 29	129.3	128.1

A change in the physico-chemical nature of the colloidal material from November 1 to December 17 was shown by the increase in the heat of wetting. The change was similar for both hardy and non-hardy alfalfas. These results support those secured by both moisture equivalent and swelling determinations. Neither moisture equivalent, swelling, nor heat of wetting were found to be an index of winter hardiness in alfalfa.

SOLUBLE MATERIAL IN ROOTS OF HARDY AND NON-HARDY ALFALFAS

The concentration of the material in solution in the plant cell influences substantially the intake, outgo, and translocation of materials in plants.

The freezing point method was used to determine the relation between winter hardiness and the quantity of soluble material in roots of hardy and non-hardy alfalfas. A 5-gram sample of air-dried root material was placed in the freezing tube and 20 cc of distilled water were added. The contents of the tube was stirred thoroughly and allowed to stand for 20 minutes. The freezing point was then determined (1), making use of a freezing bath with a temperature of —2.5° C. The contents of the tube was super-cooled about 1 degree before solidification was induced. The results are given in Table 11.

TABLE 11.—*Freezing point depression of roots of hardy and non-hardy alfalfas during October, November, and December.*

Date roots were dug, 1934	Fertilizer treatment		Freezing point depression, °C		
	Kind	Date applied, 1934	Hardigan	Utah Common	Arizona Common
Oct. 21	0-8-24	Sept. 4	—0.56°	—	—0.56°
Nov. 6	None	—	—0.61°	—	—0.60°
Nov. 6	0-8-24	May 29	—0.60°	—	—0.57°
Nov. 6	0-8-24	Sept. 4	—0.62°	—	—0.61°
Nov. 6	Nitrate soda	Sept. 4	—0.66°	—	—0.63°
Nov. 24	None	—	—0.64°	—	—0.63°
Nov. 24	0-8-24	May 29	—0.68°	—	—0.67°
Dec. 17	None	—	—0.52°	—0.53°	—0.53°
Dec. 17	0-8-24	May 29	—0.71°	—0.70°	—0.69°
Dec. 17	0-8-24	Sept. 4	—0.67°	—0.68°	—0.66°
Dec. 17	Nitrate soda	Sept. 4	—0.68°	—0.67°	—0.67°

The soluble material in a small number of undried samples was determined by the freezing point method. Immediately upon digging, the roots were washed and ground after removing the external moisture. The determinations were made without addition of water. The freezing point depression of the Hardigan roots averaged —1.56° C and of the Arizona Common roots —1.50° C, when the roots were dug December 17. The results showed little difference in the concentration of soluble material in the roots of hardy and non-hardy alfalfas when measured by the freezing point method. This method cannot be used, therefore, to measure the winter hardiness of strains of alfalfa.

DISCUSSION

The relative winter hardiness of the various strains of alfalfa has been quite successfully determined by means of field tests. In order to insure a high degree of accuracy, the field tests must extend over a long period of time. A simple laboratory test for predicting winter hardiness would aid the agronomist in determining the relative winter hardiness of the different strains of alfalfa and also assist in explaining the phenomenon of winter hardiness. In this paper are presented data from comparative studies of roots of hardy and non-hardy strains of alfalfa including determination, by electrical conductivity, of soluble material liberated through submission to low temperatures; chemical composition; moisture equivalent, swelling, and heat of wetting of finely ground root material; amount and rate of loss of moisture; and respiration. These are factors which it was thought might in part determine or explain the phenomenon of winter hardiness.

The electrical conductivity method was found useful in measuring the relative degree of hardening which had taken place in the alfalfa roots at the time the tests were conducted. No differences in hardening between hardy and non-hardy alfalfa were found on October 16, but marked differences were found on November 23, and at later dates. The varietal differences agreed with the results of previously conducted field tests. Hardening was found to develop most rapidly in the upper portion of the tap roots, while it was delayed in the lower portion and in the small lateral and hair roots. A heavy application of an 0-8-24 fertilizer on September 4 caused hardening to develop much more slowly during November and December.

Even though the electrical conductivity method was of value in determining the relative winter hardiness of different lots of alfalfa, it did not offer an explanation of the phenomenon of winter hardiness.

Three hypotheses may be suggested to account for the different degrees of winter hardiness found in the different strains of alfalfa, as follows:

1. Winter hardiness may be caused by a physico-chemical difference in the roots of hardy and non-hardy alfalfas, due to the condition of the material (whether colloidal, in solution, etc.) and composition (whether present as sugar, starch, and protein), and the structure of the tissue present. Factors such as heat of wetting, swelling, moisture equivalent, freezing point depression, chemical analysis, and the amount and rate of loss of moisture afford good indices of physico-chemical differences. These indices showed that there were no physico-chemical differences present in the roots of hardy and non-hardy alfalfas, therefore, affording no support for this hypothesis.

2. Winter hardiness may be caused by bio-chemical or functional differences brought about by the secretion of substances such as enzymes and hormones, and these differences reflected in the energy release in the cell protoplasm. The rate of respiration was used as and index of energy release and was found to be the same for both hardy and non-hardy alfalfas. The work of Dexter (8) and Tysdal (19) support these results. The acceptance of this hypothesis is not justified.

3. Winter hardiness is an hereditary factor transmitted from generation to generation. This hypothesis has not been worked out in detail by the geneticists and plant breeders. However, the behavior of succeeding generations of Hardigan, Grimm, Utah Common, Arizona Common, etc., in transmitting different degrees of winter hardiness affords sufficient evidence to warrant the acceptance of this hypothesis.

CONCLUSIONS

A search was made to find factors that could be used in the laboratory to predict the relative winter hardiness of alfalfas.

The results showed that the relative degree of injury of alfalfa roots by low temperature was indicated by electrical conductivity and in this manner the relative winter hardiness of different lots of alfalfas was determined.

No direct relationship was found to exist between winter hardiness and heat of wetting, swelling, moisture equivalent, freezing point, chemical composition, respiration, and amount and rate of loss of moisture in roots of hardy and non-hardy alfalfas.

Heredity is the most plausible explanation of the phenomenon of winter hardiness.

For the time being it is necessary to adhere to field tests aided by electrical conductivity tests for determining the relative winter hardiness of different lots of alfalfas.

LITERATURE CITED

1. Bouyoucos, G. J. The freezing point method as a new means of measuring the concentration of the soil solution directly in the soil. Mich. Agr. Exp. Sta. Res. Bul. 24. 1915.
2. ————. Heat of wetting as a new means of estimating the colloidal material in soils. Soil Science, 19 : 153–162. 1925.
3. ————. A new, simple, and rapid method for determining the moisture equivalent of soils, and the role of soil colloids on this moisture equivalent. Soil Science, 27 : 233–240. 1929.
4. ————. Simple and rapid methods for ascertaining the existing structural stability of soil aggregates. Jour. Amer. Soc. Agron., 27 : 222–227. 1935.
5. Chandler, W. H. The killing of plant tissue by low temperature. Mo. Agr. Exp. Sta. Res. Bul. 8. 1913.
6. Dexter, S. T., Tottingham, W. E., Graver, L. F. Preliminary results in measuring the hardiness of plants. Plant Phys., 5 : 215–223. 1930.
7. ————, ————, ————. Investigations of the hardiness of plants by measurement of electrical conductivity. Plant Phys., 7 : 63–78. 1932.
8. ————. Respiration rate and enzyme activity as related to the hardened condition of plants. Plant Phys., 9 : 831–837. 1934.
9. Gortner, R. A. Outlines of Biochemistry. New York: John Wiley & Sons. 1929. (Pages 231–241.)
10. Graber, L. F., Nelson, N. T., Luekel, W. A., and Albert, W. B. Organic food reserves in relation to the growth of alfalfa and other perennial herbaceous plants. Wis. Agr. Exp. Sta. Res. Bul. 80. 1927.
11. Harvey, R. B. Hardening process in plants and developments from frost injury. Jour. Agr. Res., 15 : 83–112. 1918.
12. ————. Annotated Bibliography of Low Temperature Relations of Plants. Minneapolis: Burgess Pub. Co. 1935.
13. Maximov, N. A. Internal factors of frost and drought resistance in plants. Protoplasma, 7 : 259–291. 1929.
14. Megee, C. R. A comparison of alfalfa strains and seed sources for Michigan. Mich. Agr. Exp. Sta. Sp. Bul. 211. 1931.
15. Newton, R. Colloidal properties of winter wheat plants in relation to frost resistance. Jour. Agr. Sci., 14 : 178–191. 1924.
16. Rosa, J. T. Investigations on the hardening process in vegetable plants. Mo. Agr. Exp. Sta. Res. Bul. 48. 1921.
17. Spurway, C. H. Soil testing. Mich. Agr. Exp. Sta. Res. Bul. 132. 1933.
18. Steinmetz, F. H. Winter hardiness in alfalfa varieties. Minn. Agr. Exp. Sta. Tech. Bul. 38. 1926.
19. Tysdal, H. M. Determination of hardiness in alfalfas by their enzymatic responses. Jour. Agr. Res., 48 : 219–240. 1934.
20. Weimer, J. L. Some factors involved in the winter killing of alfalfa. Jour. Agr. Res., 39 : 263–283. 1929.

SEED PRODUCTION OF SPACE-ISOLATED VS. BAGGED MOTHER BEETS AND A DISCUSSION OF SOME FACTORS INFLUENCING THE LATTER[1]

H. L. KOHLS[2]

THE most commonly used method of controlling pollination of sugar beets under Michigan conditions has been by space isolation as described by Down and Lavis (6).[3] The labor cost required to isolate a mother beet in a city garden naturally restricts the number of mother beets that can be used in any one season. The few hundred beets usually isolated in any one year are only a fraction of the number of selfings made by any corn breeder. This difference is still further enhanced by the factor of self-sterility found in many mother beets and by unavoidable losses of individual plants through one cause or another.

Various methods have been used by plant breeders for controlling pollination of beets. Space isolation has proved very satisfactory when care was taken to destroy nearby seed plants of Swiss chard and red garden beets (6, 2). Of the bagging material used, light-weight parchment and light-weight Kraft grocery bags have been the most satisfactory (15, 1, 6, 7, 2, 11, 16, 4). The bags of the heavier weight paper and also of glassine and cellophane seldom have seed set in them (16, 10, 4). Some workers have found that cages made of finely woven cloth have been very satisfactory in some cases (17, 2), but in others a great amount of crossing took place (14, 6).

Lack of success of seed production under bags has been attributed to various causes such as type of isolator (15, 11, 4); high temperature (17, 6, 2); high relative humidity (2); no insects to carry pollen (3, 13); protandrous nature of the beet (13); and inheritance of self-sterility (9, 2, 8).

The factors influencing the set of seed on isolated mother beets appear to be complex and much more intensive study is necessary to determine the effect of each factor and the interaction of the several factors. Seed production studies on mother beets, isolated under paper bags, were begun in 1930 in two widely separated localities and extended to a third locality in 1932. The data obtained in these experiments are for 4 years at East Lansing, 4 years at Burt Lake, and 2 years at Traverse City.

METHODS AND MATERIALS USED

The method of isolation of mother beets by bags and by space was the same as that described by Down and Lavis (6). A number of red garden beets were

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[3] Figures in parenthesis refer to "Literature Cited," p. 705.

distributed systematically over the area in the bagging experiment to determine whether or not foreign pollen entered the bags. Crosses of red garden beets on sugar beets are easily detected as the red color of the red garden beet is dominant in the F_1 generation.

The mother beets used for bagging were selected from commercial and inbred lots. All types of bagging material were placed on each mother beet wherever possible. This reduces greatly the possibility of the differences obtained between types of bagging material being due to differences in the self-sterility of the individual mother beets. Fifteen kinds of bags were used in these experiments, a description of which is given in Table 1.

TABLE 1.—*Description of bags used in experiments.*

Reference No.	Material	Size of bag
1	40 lb. grease-proof white parchment	2 x 4 x 11 in.
2 S	30 lb. white parchment	4 x 11 in.
2 M	30 lb. white parchment	6 x 18 in.
2 L	30 lb. white parchment	8½ x 23 in.
3	40 lb. white parchment	2 x 4 x 11 in.
4	40 lb. white parchment	6 x 18 in.
6	40 lb. Mosinee (brown grocery)	10 lb.
7	50 lb. Union Hemp (extra heavy brown grocery)	12 lb.
8	30 lb. Union Tiger (Kraft grocery)	10 lb.
11 S	Hard finish filter paper	4 x 11 in.
11 M	Hard finish filter paper	6 x 18 in.
11 L	Hard finish filter paper	8½ x 23 in.
18	40 lb. Tuff Buff (Kraft grocery)	5 lb.
19	Cloth bag covered with paraffin emulsion	6 x 12 in.
20	Pyralin (water proof and transparent tube)	3 in. dia. x 16½ in.
21 S	No. 450 cellophane	4 x 11 in.
21 M	No. 450 cellophane	6 x 18 in.
22	No. 600 cellophane	6 x 18 in.
23 S	Glassine (weight not known)	4 x 11 in.
23 M	Glassine (weight not known)	6 x 18 in.
23 L	Glassine (weight not known)	8½ x 23 in.
24	Paper flour bags, 50 lb. white parchment	¼ bbl.
25	Paper flour bags, heavy white paper, inner surface blue	¼ bbl.
26	Paper flour bags, heavy brown hemp	¼ bbl.

Some of the bags were found to be practically useless as they had very few seeds set in them. The results with Nos. 1, 3, 4, 20, 21, 22, 23, 24, 25, and 26 are omitted for that reason.

PRESENTATION OF DATA

SPACE ISOLATION VS. PAPER BAGS

The most satisfactory bag tested for 3 or more years to control the pollination of mother sugar beets was one made from 30 lb. white vegetable parchment 8½ inches wide and 23 inches long, designated as No. 2. A comparison of the results obtained from this bag and from space isolation in city gardens is shown in Tables 2 and 3.

The data in Tables 2 and 3 indicate that control of pollination by space isolation of beets had two advantages over control of pollination by the use of paper bags. These were (a) the average production of seed per beet was 25.51 grams for those space isolated as

TABLE 2.—*Date obtained from mother beets space isolated in city gardens.*

	1930	1931	1932	1933	Average
No. beets isolated	518	571	639	307	508.75
No. beets with seed stalks	431	427	315	199	343.00
Percentage beets with seed stalks that set seed	87.94	88.29	90.79	76.38	87.03
Percentage with seed of all beets isolated	73.17	66.02	44.76	49.51	58.68
Yield of seed per plant that set seed, grams	32.40	25.21	18.31	26.13	25.51

TABLE 3.—*Data obtained from mother beets bagged with one No. 2 (30 lb. white vegetable parchment) bag each.*

	1930	1931	1932	1933	Average
No. beet plants bagged	37	51	97	87	57.87
No. beet plants with undamaged bags	25	25	87	45	44.75
Percentage beet plants with undamaged bags that set seed	40.00	44.00	36.78	40.00	39.01
Percentage all bagged beet plants with seed set	27.02	21.57	32.99	20.69	26.10
No. seeds per plant of all bagged beets with seed set*	32.40	76.55	41.44	74.72	54.04

*70 seeds weigh about 1 gram.

compared to less than a gram for those bagged with paper bags; and (b) 87.03% of the space-isolated beets with seed stalks set seed as compared to only 39.01% of beet plants with undamaged bags which had seed set in them.

Considering all beets, isolated and bagged, the percentage of space-isolated beets bearing seed was more than double that for the bagged beets.

The following advantages accruing from bagging beets to control pollination were found: (a) Less time required for planting. A larger number of beets can, therefore, be planted early in the spring without serious interference from heavy rains. Early planting is essential for seed production since late-planted beets usually do not develop seed stalks. (b) Practically no crossed seed was found under the bags. Beets grown in 1933 from the bagged seed showed that 6 bags out of 166 contained a trace of hybrid seed. No indication of cross fertilization was found in the bagged seed planted in 1934. (c) Accidental destruction of mother beets, as often happens with beets isolated in city gardens, is almost entirely eliminated.

The comparative disadvantage in the small amount of seed produced on beets under bags can be decreased by placing more than one bag on a beet. Data on this subject are not available for the No. 2 bags, but they are available for the No. 8 bags (Table 4). These data show that the percentage of beets with seed set and the number of seeds per plant was increased. These increases, however, were not in proportion to the number of sacks used, and the yield of seed per plant remained much below that of the space-isolated mother beets.

TABLE 4.—*Comparative results from mother beets bagged with one to five No. 8 (10 lb. Union Tiger grocery) bags in 1933.*

	One bag per plant	Five bags per plant
No. beet plants bagged	64	213
No. beet plants with one or more undamaged bags	42	182
Percentage beet plants with undamaged bags with seed set	33.33	51.63
Percentage all bagged beet plants with seed set	21.88	44.60
No. seeds per plant*	45.86	57.15

*70 seeds weigh about 1 gram.

FACTORS INFLUENCING SET OF SEED WITHIN BAGS

Size of bag.—The size of bag also influenced the set of seed. The data shown in Table 5 indicate that the large bags were more easily damaged by wind than the small bags, but the former had a higher percentage of undamaged bags with seed produced in them and had more seeds per bag than the latter.

TABLE 5.—*The effect of size of bag upon the set of seed.**

Bags used	Total No. bags	Undamaged bags %	No. bags with seed	Undamaged bags with seed %	Per cent all bags with seed	Average no. seeds per bag with seed	Average no. seeds per bag for all bags used
2 S	513	81.84	154	36.84	30.02	27.58	8.28
2 M	446	70.40	134	42.68	30.04	38.88	11.68
2 L	456	61.40	133	47.50	29.17	55.89	16.30

*The data are a summary of 4 years' (1930–33) work at East Lansing and Burt Lake and 2 years (1932 and 1933) at Traverse City.

Shading and shaking.—A group of mother beets were divided into two lots. One lot was shaded by fastening burlap sacks to stakes on the east, south, and west sides of the beets in such a manner that the sun did not shine on the bags. The bags were shaded from the time they were put on until harvest time. The second lot was not shaded. The bags on one-half of the beets in each lot were shaken daily for about 3 weeks after they were put on. The data obtained are presented in Table 6.

TABLE 6.—*The effect of shading and shaking the bags upon the set of seed at East Lansing in 1931.*

Bags used	Shaken		No treatment		Shaded and shaken		Shaded	
	No. undamaged bags	Seed set %	No. undamaged bags	Seed set %	No. undamaged bags	Seed set %	No. undamaged bags	Seed set %
2 S	59	38.98	43	37.21	17	23.53	25	12.00
2 M	43	53.49	51	29.41	17	11.76	23	13.04
2 L	36	38.89	25	44.00	12	25.00	19	5.26
Average		43.48		35.29		19.57		10.45

Shaking the bags daily during the flowering period was beneficial to the set of seed. Shading the bags was detrimental to seed production. Shaking the shaded bags daily increased the percentage of shaded bags that set seed, but the percentage was much below that of the groups not shaded.

Type of isolator.—The data obtained and shown in Tables 7, 8, and 9 varied greatly for the different kinds of material used and for the different locations. The materials, however, had definite relative values for the control of pollination and these values at the three stations were usually in the following order: Nos. 18, 2, 8, 6, and 7.

TABLE 7.—*Data obtained from various kinds and sizes of bags on mother beets for control of pollination at East Lansing, Mich., 1930–33.*

Bags used	No. years tested	Total No. bags	Undamaged bags %	No. bags with seed	Undamaged bags with seed %	Per cent all bags with seed	Average no. seeds per bag with seed	Average no. seeds per bag for all bags used
2 S*	4	311	86.45	83	30.86	26.69	32.54	8.68
2 M*	4	257	82.06	71	33.65	27.63	40.62	11.68
2 L*	4	272	66.91	71	39.01	29.78	54.04	14.11
6	2	169	70.41	21	17.65	12.43	33.10	4.11
7	3	193	84.97	26	15.85	13.47	29.19	3.93
8	3	189	66.67	35	27.78	18.52	39.00	7.22
11 S	1	6	83.33	2	40.00	33.33	3.00	1.00
11 M	1	7	71.42	1	20.00	14.29	9.00	1.29
11 L	1	8	75.00	3	50.00	37.50	10.00	3.75
18	1	73	86.30	26	41.27	35.62	47.35	16.86
19	1	69	100.00	19	27.54	27.54	27.32	7.52

*Undamaged bags only were counted in 1930. Corrections were made on a basis of their performance in other years.

TABLE 8.—*Data obtained from various kinds and sizes of bags on mother beets for control of pollination at Traverse City, Mich., 1932 and 1933.*

Bags used	No. years tested	Total No. bags	Undamaged bags %	No. bags with seed	Undamaged bags with seed %	Per cent all bags with seed	Average no. seeds per bag with seed	Average no. seeds per bag for all bags used
2 S	2	84	77.38	33	50.77	39.29	38.79	15.24
2 M	2	78	56.41	30	68.13	68.18	54.27	20.87
2 L	2	69	53.62	28	75.68	40.58	87.11	35.35
6	2	63	61.90	23	58.97	36.51	47.78	17.44
7	2	59	81.36	29	60.42	49.15	35.97	17.68
8	2	62	59.67	30	81.08	48.39	49.60	24.00
18	1	49	95.92	34	72.34	69.39	52.79	36.63

This placing is very close to the placing of Nos. 2, 18, 8, 6, and 7, as judged by the amount of light that appeared to pass through these bags when held before a lamp, and suggests a very close relationship between set of seed and the moisture content in the bags and the amount of light that passes into the bags.

TABLE 9.—*Data obtained from various kinds and sizes of bags on mother beets for control of pollination at Burt Lake, Mich., 1930–33.*

Bags used	No. years tested	Total no. bags	Undamaged bags %	No. bags with seed	Undamaged bags with seed %	Per cent all bags with seed	Average no. seeds per bag with seed	Average no. seeds per bag for all bags used
2 S	4	118	71.19	38	45.24	32.20	7.00	2.25
2 M	4	111	53.15	33	55.93	29.73	21.18	6.30
2 L	4	115	53.04	34	55.74	29.57	34.03	10.06
6	2	64	92.19	19	32.20	29.69	21.95	6.52
7	3	105	95.24	30	30.00	28.57	10.60	1.03
8	3	89	83.15	28	37.84	31.46	27.07	8.52
18	1	25	100.00	11	44.00	44.00	13.45	5.92

Climate.—It was found that a much higher percentage of the undamaged bags at Burt Lake and Traverse City had seed set in them than at East Lansing (Table 10), except in the case of the planting at Burt Lake in 1933. This exception was due, at least in part, to

TABLE 10.—*A comparison of the percentage of undamaged bags that had seed set in them.*

Bags used	1930	1931	1932	1933
	East Lansing			
2 S	26.19	37.21	21.92	42.03
2 M	39.22	29.41	23.68	38.21
2 L	40.00	44.00	36.78	40.00
Average	31.39	35.29	27.97	43.53
	Burt Lake			
2 S	57.14	46.15	48.78	34.78
2 M	71.43	100.00	56.67	26.67
2 L	75.00	45.00	65.38	45.45
Average	66.67	55.00	55.67	34.69*
	Traverse City			
2 S	—	—	50.00	51.36
2 M	—	—	55.56	71.43
2 L	—	—	57.14	80.00
Average	—	—	52.27	66.67

*Most of the mother beets were infected with disease before planting.

the fact that more of the mother beets showed signs of disease infection before planting at Burt Lake than did the mother beets at the other stations. The higher percentage set of seed could not be explained on soil fertility differences alone as the mother beets at East Lansing were grown on soil heavily fertilized while the beets at Traverse City were grown on sandy unfertilized soil. The soil at Burt Lake was more sandy than at East Lansing, but it had been a grass sod and plowed before planting the beets. The climatic differences, such as temperature and rainfall, apparently were great enough to influence the set of seed of sugar beets.

SUMMARY

A much larger amount of seed can be obtained from mother beets when isolated by space than when isolated by bagging. This advantage is offset by (a) the longer time required for space isolating; (b) danger of bad weather preventing isolation until warm weather begins, which decreases the number of mother beets sending up seed stalks; (c) danger of crossing with Swiss chard or garden beets; and (d) danger of destruction by careless individuals. The disadvantage of small seed production under bags is offset to some extent by (a) small chance of cross pollination, and (b) no destruction of mother beets by careless individuals.

Seed production under bags per mother beet can be increased by (a) placing several bags on each mother beet; (b) using thin bags; (c) using large bags; (d) shaking bags daily during flowering period; (e) not shading the bags; and (f) possibly by growing the mother beets in a cool section of the state.

LITERATURE CITED

1. Archimovitch, A. Regulation of pollination in sugar beet. Bul. Belaya Cerkov. Plant Breed. Sta. of the Sugar Trust, 4 (series 2): 1–41. 1928.
2. ————. On the inbreeding method applied to the sugar beet. Trans. Belaya Cerkov. Plant Breed. Sta., 6, pt. 3 : 1–62. 1931.
3. Artschwager, Ernst. Development of flowers and seed in the sugar beet. Jour. Agr. Res., 34 : 1–25. 1927.
4. Brewbaker, H. E. Self-fertilization in sugar beets as influenced by type of isolator and other factors. Jour. Agr. Res., 48 : 323–337. 1934.
5. Charetschko-Sawitzkaja, E. Method and technique of artificial hybridization in beet. Wauk. Zapiski Tsukr. Prom., 13 : 613–632. 1931.
6. Down, E. E., and Lavis, C. A. Studies on methods for control of pollination in sugar beets. Jour. Amer. Soc. Agron., 22 : 1–9. 1930.
7. Grinko, T. F. Self-pollination in the sugar beet. Proc. U.S.S.R. Congr. Genet. Plant and An. Breed., 4 : 111–119. 1930.
8. Kohls, H. L., and Down, E. E. Influence of inbreeding and selection on seed production of space-isolated mother beets. Jour. Amer. Soc. Agron., 26 : 327–332. 1934.
9. Magruder, Roy. The production of table beet seed under glassine bags. Proc. Amer. Soc. Hort. Sci., 26 : 20–25. 1930.
10. ————. Self-sterility and fertility in garden beets as indicated by seed production under paper bags. Proc. Amer. Soc. Hort. Sci., 28 : 328–331. 1932.
11. ————. The effect of kind of paper bags on the production of selfed table beet seed under bags. Proc. Amer. Soc. Hort. Sci., 29 : 442–444. 1933.
12. Pack, Dean A. Time of year to plant mother beets for seed production. Jour. Agr. Res., 30 : 811–818. 1925.

13. REED, ERNEST. Sterility and inbreeding in beets. Mem. Hort. Soc. of New York, 3 : 59–63. 1927.

14. SHAW, HARRY B. Self, close, and cross-fertilization of beets. Mem. New York Bot. Gard., 6 : 149–152. 1916.

15. STEWART, GEORGE, and TINGEY, D. C. A method for controlling pollination of sugar beets. Jour. Amer. Soc. Agron., 19 : 126–128. 1927.

16. ———. Some effects of inbreeding of sugar beets. Jour. Amer. Soc. Agron. 25 : 237–258. 1933.

17. VILMORIN, J. L. de L'Heredite chez la beterava cultivee. Paris: Gauthier-Villars et Cie. 1923.

EFFECT OF TILLERS ON THE DEVELOPMENT OF GRAIN SORGHUMS[1]

A. T. BARTEL, J. H. MARTIN, AND R. S. HAWKINS[2]

IN most grain sorghum fields the plants are spaced sufficiently wide to allow the development of tillers. The highest yields of grain in freely-tillering varieties of milo and feterita usually have been obtained with plant spacings that produced considerable tillering (4, 5, 6, 8).[3] The tillers often bear a considerable portion of the total grain yield, although under normal conditions the heads on the main stalks are larger than those on the tiller stalks. This investigation was undertaken to determine the effect of tillers and their removal upon the development of the main stalk and upon the total grain yield of Dwarf hegari.

REVIEW OF LITERATURE

Tillers have frequently been regarded as detrimental in grain sorghums and the selection of seed heads from plants without tillers has been recommended (1, 7). More recent and complete investigations (5, 6), however, have suggested the undesirability and futility of these early recommendations.

Hastings (3) recommended a rate of planting sufficiently heavy to prevent tillering in milo at San Antonio, Tex., finding that attacks of the sorghum midge could be reduced by early and uniform flowering. Plants with a lesser number of tillers resulted in a larger number of erect heads, more uniformity, and higher grain yields under these special conditions.

Tillers, or suckers as they are often called, have been a problem in many crop plants, especially corn. As early as 1909, Williams (10) removed the suckers in corn to determine if they were injurious to the yields. Reductions in the weight of grain per stalk, percentage grain to cob, and yield of stover were obtained by removing the suckers from the plants. Dungan (2) defoliated the main stalks of corn at the early milk stage, removing the suckers from some plants and allowing them to remain on others. Significant increases in weights were obtained from the plants having suckers over those from which the suckers had been removed. Nourishment for the main stalks was received from the suckers when they were left on the plants.

The physiological relations between the tillers and the main stalk of wheat have been worked out by Smith (9). He observed but slight translocation between different tillers of a plant after flowering. His results indicate that considerable photosynthesis can take place on the surface of the culms when the leaves have been removed. Any water taken up by the roots is distributed evenly to all of the tillers of a plant.

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[3] Reference by numbers in parenthesis is to "Literature Cited," p. 714.

METHODS

The experiments reported in this paper were carried on under irrigation during the summers of 1931, 1932, and 1933 at the University Farm, Tucson, Ariz. The variety Dwarf hegari was used in all the tests because it tillers readily and is also the principal grain sorghum grown in this region. The seed was planted on normal planting dates and the plants thinned to a distance of approximately 15 inches soon after they were up. The plants received normal irrigation, except that in 1932 and 1933 an additional series was grown in which no irrigation water was applied after early jointing.

The tillers were removed from the plants at the following stages: (a) As soon as they formed, (b) when the leaves of the main stalk had unrolled, and (c) at heading of the main stalk. The leaves of the main stalk were removed at (a) unrolling, (b) heading, and (c) at the soft dough stage of the kernels. The unrolling of the leaves of the main stalk occurs 2 to 3 weeks before flowering. Removing the leaves of the main stalk earlier than 3 weeks before flowering resulted in barren stalks where the tillers were also removed. The term "heading" refers to the time when the head on the main stalk flowers. In cases where the tillers were removed as they formed, there was a continual removal of tillers until no more developed. In tests where the leaves of the main stalk were removed at unrolling, the new growth was cut off on alternate days until leaf growth ceased with the appearance of the head.

The removal of leaves and tillers at heading was conducted on an individual plant basis; that is, each plant was taken as a unit, and it was not until the main head had flowered that its leaves and tillers were removed. In the other determinations, all the plants were treated as a group. For example, when the tillers and leaves were removed at unrolling, all the plants were so treated regardless of their number of leaves or stage of unrolling.

All the weights recorded are in grams and on an air-dry basis. No stalk weights were obtained in 1932.

In the normal irrigated plats a total of 90 plants were used for each treatment in 1931, 50 plants in 1932, and 75 plants in 1933. Fifty plants were used for each determination in the plats receiving a single irrigation in 1932 and 60 plants in 1933.

RESULTS OBTAINED

The results obtained from the removal at different stages of the tillers and leaves of the main stalk of the plants grown under normal irrigation are presented in Table 1 and in Figs. 1 and 2.

When the main stalks were defoliated at unrolling, i. e., 2 or 3 weeks before flowering, an increase in the weights and number of grains per head occurred as the length of time the tillers were allowed to remain on the plants increased. The average weight of seed per head was 3.6 grams on stalks from which the tillers were removed as they formed, but when the tillers were allowed to remain on the plants the average weight was 16.5 grams.

The heads on the stalks defoliated at the early unrolling stage were very small (Figs. 2 and 3).

In no case did all the main stalks head when their leaves were removed at unrolling and the weights shown are averages for the heads that were harvested. During the 3 years the experiments were conducted an average of 23.4% of the main stalks headed when the

TABLE 1.—*Effect of defoliation and tiller removal upon weights of stover and grain of Dwarf hegari.*

Stage of tiller removal	Weight in grams of										Threshing percentage of heads, 3-year average
	Stover per stalk		Grain per head				100 kernels				
	1931	1933	1931	1932	1933	Av.	1931	1932	1933	Av.	
Main Stalk Defoliated When Upper Leaves Were Unrolled											
When formed	19.9	16.3	2.1	5.5	3.1	3.6	0.72	0.90	1.42	1.01	60.0
Unrolling	26.8	—	4.0	6.7	0.0	3.6	0.77	1.10	—	0.94	75.4
Heading	21.8	23.4	4.5	10.0	10.3	8.3	0.94	1.30	1.52	1.25	69.8
None — Main stalk	21.6	39.1	6.8	21.7	20.9	16.5	1.62	1.82	2.70	2.05	83.8
Average tiller	56.4	80.4	37.8	35.4	59.2	44.1	2.74	2.15	2.89	2.59	84.7
All tillers per plant	—	—	85.5	72.5	137.2	98.4	—	—	—	—	—
Main Stalk Defoliated at Heading Stage											
When formed	49.1	81.4	11.7	23.9	32.9	22.8	0.61	0.81	1.29	0.90	59.5
Unrolling	54.3	58.9	12.9	24.5	22.7	20.0	0.65	1.14	1.06	0.95	59.5
Heading	48.9	48.9	12.6	19.0	19.6	17.1	0.65	0.92	0.86	0.81	61.0
None — Main stalk	54.5	74.1	35.8	37.0	60.9	44.6	1.63	1.65	2.48	1.92	79.5
Average tiller	48.9	68.8	26.9	26.0	48.5	33.8	2.51	2.09	2.66	2.42	81.8
All tillers per plant	—	—	53.4	52.8	125.8	77.3	—	—	—	—	—
Main Stalk Defoliated at Milk Stage											
When formed	80.3	121.6	66.3	82.0	94.6	81.0	2.11	2.46	3.11	2.56	81.7
Unrolling	82.3	98.6	69.3	64.5	79.2	71.0	2.34	2.61	2.91	2.62	81.3
Heading	74.1	99.2	69.1	62.2	74.9	68.7	2.36	2.41	2.96	2.58	82.7
None — Main stalk	63.6	77.4	57.6	48.2	68.8	58.2	2.24	2.17	2.74	2.38	82.2
Average tiller	62.2	69.3	33.7	25.4	50.8	36.6	2.65	2.33	2.81	2.60	81.7
All tillers per plant	—	—	56.8	51.9	90.7	66.5	—	—	—	—	—
Main Stalk Not Defoliated											
When formed	121.2	194.5	89.2	77.1	100.8	89.0	2.80	2.73	3.45	2.99	85.5
Unrolling	141.0	158.0	83.0	83.9	95.2	87.4	3.16	2.81	3.60	3.19	83.1
Heading	145.2	174.7	73.9	57.3	76.0	69.1	3.00	2.54	3.21	2.92	83.9
None — Main stalk	84.7	86.4	66.7	47.6	70.8	61.7	2.61	2.09	3.02	2.57	83.9
Average tiller	54.0	75.2	30.2	26.5	48.8	35.2	2.58	2.15	2.75	2.49	82.8
All tillers per plant	—	—	61.2	56.6	91.4	69.7	—	—	—	—	—

tillers were removed as they formed, 14.1% when the tillers were removed at unrolling, 73.1% when the tillers were removed at heading, and 60.0% of the main stalks headed when the tillers were allowed to remain on the plants. No heads were produced in 1933 when the leaves of the main stalk and the tillers were removed at unrolling. In the other determinations practically 100% of the main stalks headed.

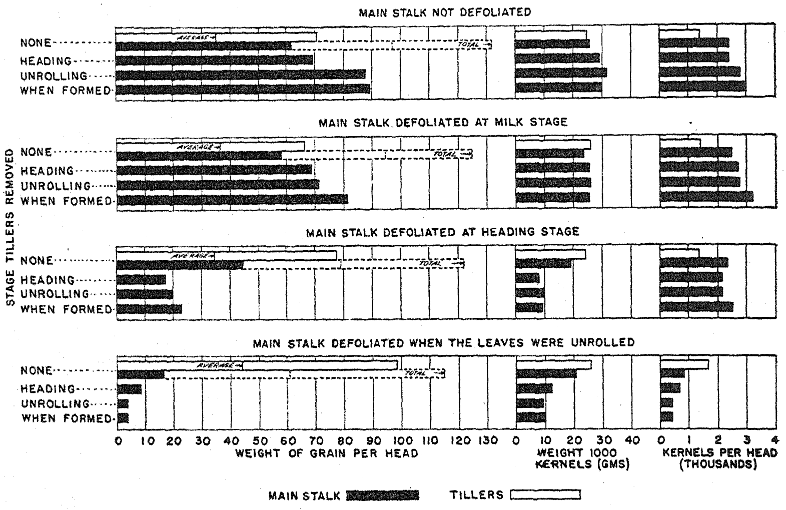

FIG. 1.—Effect of defoliation and tiller removal on weight of grain per head, weight of 1,000 kernels, and number of kernels per head in Dwarf hegari.

It is evident that tillers were beneficial to the development of the main stalk when the leaves of the main stalk were removed as early as 2 or 3 weeks previous to flowering. The tillers were much heavier than the main stalks after defoliation at this stage.

When the leaves of the main stalk were removed at the heading stage, the sooner the tillers were removed, the higher was the average stalk weight and average weight of grain per head. Tillers that were removed were thus eventually detrimental to the development of the main stalk under these conditions. However, when the tillers were allowed to remain on the plants, a decided increase in the main stalks was obtained in stalk weight, weight of grain per head, and weight of 100 kernels. The number of kernels per head (Fig. 1) was nearly the same, so the increased size of kernel was due to food material supplied by the tillers.

The average weights of seed per head on plants defoliated at heading were from two to six times those on the corresponding plants defoliated at unrolling. With the greatly increased number of kernels per head on the plants defoliated in the heading stage, and with no leaves or tillers for further synthesis, the reduced weight of kernel observed was to be expected.

When the leaves of the main stalks were removed at the soft dough stage or allowed to remain, a gradual decrease in the weight of the main stalk resulted from delaying tiller removal. The differences were due chiefly to the development of more kernels when the tillers were removed early. When the tillers were allowed to remain on the plants, the main stalks produced less grain than did those of the plants from which the tillers were removed. The detrimental effect of tillers upon the main stalks was very noticeable both in the stover and grain weights. The tillers, however, produced much more than enough to offset the smaller main stalks.

The number of kernels per head (Fig. 1) was slightly larger and the weight of kernels considerably greater on the stalks undefoliated, or defoliated in the milk stage, than on those defoliated at the heading stage. The threshing percentage (percentage of grain in the heads) is determined to a considerable extent by the size of kernel (Table 1) and consequent-

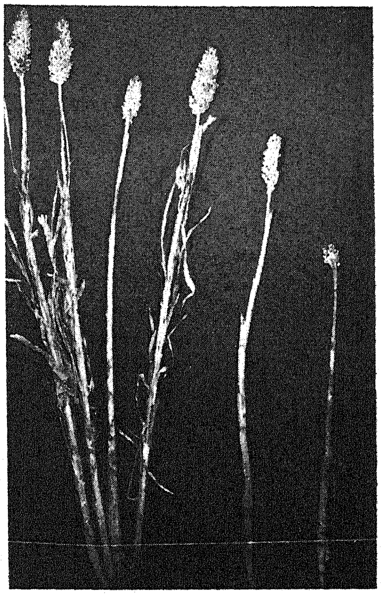

FIG. 2.—Plants of Dwarf hegari showing effect of defoliation and tiller-removal on plant development. A, tillers not removed, main stalk defoliated at flowering; B, tillers removed and main stalk defoliated at flowering; C, tillers removed and main stalk defoliated 3 weeks before flowering.

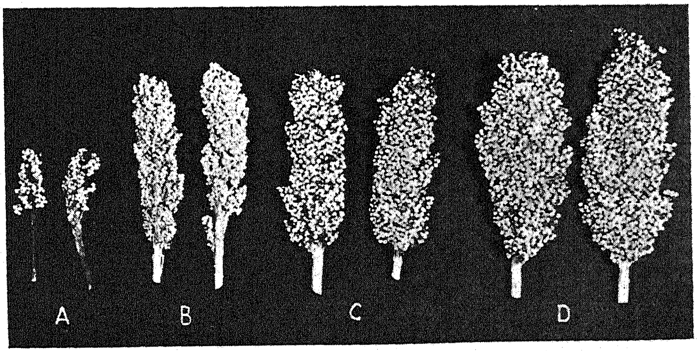

FIG. 3.—Heads of Dwarf hegari from main stalks, defoliated 3 weeks before flowering (A, B, C) and from plants not defoliated (D). A, tillers removed when formed; B, tillers removed when main stalk headed; C and D, tillers not removed.

ly is low in the main heads of the plants from which the leaves and tillers were removed in the heading stage or earlier.

In 1933 an additional experiment was carried on in which the tillers were defoliated a few days after flowering while the leaves of the main stalk were allowed to remain on some plants but in others were removed a few days after flowering. These results are shown in Table 2.

TABLE 2.—*Effect of defoliation of the main stalks upon the development of defoliated tillers on the same plants.*

Stalk	Weight in grams of			Threshing percentage of heads
	Stover	Grain per head	100 kernels	
	Main Stalks Defoliated			
Main	39.4	15.4	1.23	70.6
Tiller	25.6	10.7	1.03	69.9
	Main Stalks Not Defoliated			
Main	69.7	62.6	2.63	85.3
Tiller	34.6	36.1	1.88	84.7

When the leaves of the main stalk were removed, the weights of stalk and grain were greater on the main stalks than on the defoliated tiller stalks. The main stalk was usually slightly larger and earlier than the tiller stalk.

There was a decided increase in the weights of the tillers when the leaves of the main stalk were allowed to remain. The weight of grain per head increased from 10.7 grams to 36.1 grams in the tiller stalk and the weight of 100 kernels was increased from 1.03 grams to 1.88 grams due to nourishment they received from the main stalks.

DEFOLIATION AND TILLER REMOVAL UNDER DROUGHT CONDITIONS

In 1932 and 1933 some of the plants received only one irrigation each year, applied in the early jointing stage. The results in general were so nearly the same as where normal irrigation was applied that the data obtained will not be presented.

The most noticeable difference between the normally-irrigated and the drought-affected plants was the reduced stalk weight in the latter, especially when the leaves and tillers were removed after the heading stage. This was undoubtedly due to the slightly shorter stalks of the drought-affected plants.

DISCUSSION

When the leaves of the main stalk were removed early, the tillers were definitely beneficial and aided in the nourishment of the main stalk. Also, when the leaves of the tiller stalks were removed and the leaves of the main stalk allowed to remain, the main stalk nourished the tiller stalks and greatly increased their weights. These results lead one to conclude that the plant juices containing organic nutrients are free to move from the tiller to the main stalk, or from the main stalk to the tiller, depending upon where the nutritional deficiency is found. The vascular connection between the main stalks and the tillers is shown in Fig. 4.

When the leaves of the main stalk were removed late in the development of the plants, as in the soft dough stage, the tillers were detrimental to the development of the main stalk. This was also true when the main stalks were not defoliated.

Although the tiller removal ("suckering") of Dwarf hegari increased the yields of undefoliated main stalks, the increase was less than the grain and stover produced by the tillers themselves. It appears that the main stalk and tillers of a plant ordinarily compete for nutrients, but it is important to remember that tillers usually develop and produce heads only when the moisture and fertility supply is sufficient for both main stalk and tiller growth. Each tiller develops a root system of its own.

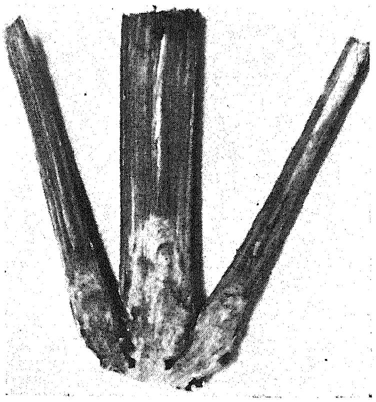

FIG. 4.—Vascular connection between main stalk and tillers of Dwarf hegari.

SUMMARY

Tillers and leaves of the main stalks of Dwarf hegari, a grain sorghum, were removed at various stages of plant development.

Tillers increased the development of the main stalks of Dwarf hegari when the leaves of the latter were removed previous to heading, and the longer the tillers were left on the plant, the greater were the weights of the main stalk.

When the leaves of the main stalk were removed at the soft dough stage of the kernels or when the leaves of the main stalk were allowed to remain, the longer the tillers were left on the plants, the lower were the weights of the main stalk. Tillers in such cases seem detrimental to the development of the main stalk but produce more than enough grain and stover to offset the decreased growth of the main stalk.

There is evidence that plant juices are free to move from the main stalk to the tillers or from the tillers to the main stalk, depending upon where the nutritional deficiency occurs. A vascular connection exists between the main stalk and tiller stalk.

The effects of the tillers on the main stalks of plants subjected to drought were about the same as on the plants receiving ordinary irrigation.

LITERATURE CITED

1. BALL, C. R. The importance and improvement of the grain sorghum. U. S. D. A. Bur. Plant Indus. Bul. 203 : 1–45. 1911.
2. DUNGAN, G. H. An indication that corn tillers may nourish the main stalk under some conditions. Jour. Amer. Soc. Agron., 23 : 662–670. 1931.
3. HASTINGS, S. H. The importance of thick seeding in the production of milo in the San Antonio region. U. S. D. A. Bul. 188. 1915.
4. KARPER, R. E. The contrast in response of kafir and milo to variations in spacing. Jour. Amer. Soc. Agron., 21 : 344–354. 1929.
5. ————, QUINBY, J. R., JONES, D. L., and DICKSON, R. E. Grain sorghum date-of-planting and spacing experiments. Texas Agr. Exp. Sta. Bul. 424 : 1–71. 1931.
6. MARTIN, J. H., *et al.* Spacing and date-of-seeding experiments with grain sorghums. U. S. D. A. Tech. Bul. 131. 1929.
7. ROTHGEB, B. E. Milo, a valuable grain crop. U. S. D. A. Farmers' Bul. 1147: 1–18. 1920.
8. SIEGLINGER, J. B. The spacing of grain sorghums. Jour. Amer. Soc. Agron., 18 : 525. 1926.
9. SMITH, H. F. The physiological relations between tillers of a wheat plant. Austr. Council Sci. and Ind. Res. Jour., 6 : 1. 1933.
10. WILLIAMS, C. B. Economic value of corn suckers. Jour. Amer. Soc. Agron., 4 : 152–157. 1912.

CORRELATING YIELD WITH PHENOLOGICAL AVERAGES TO INCREASE EFFICIENCY IN WHEAT BREEDING[1]

B. G. MOUSSOUROS AND D. C. PAPADOPOULOS[2]

A great deal of work has been done in Greece during the last decade to improve the acre yield of wheat. An important part of this work has to do with testing and propagating imported varieties and selections from native varieties. Due to the great diversity in climate and soil types which characterize Greece, as well as to the great variation in weather conditions from year to year, this task involved a good deal of time and energy and every possible effort should be put forth in carrying on an efficient wheat breeding program with the limited means and personnel available.

Such efforts should be directed not only toward defining ecological areas and properly locating the experimental fields, but also in establishing general principles and specific criteria which would aid in selecting strains from local stock and varieties created abroad without waiting for yields. Furthermore, certain of these principles and criteria should be employed to determine how long one should continue testing promising varieties, or at what stage of the testing process the undesirable ones should be discarded.

A review of the literature on this subject indicates that formerly agriculturalists who dealt with wheat problems in this country thought of the introduction from abroad of earlier varieties as one of the most effective means for improving the wheat yield on the theory that in eastern Greece, where the annual rainfall ranges from 15 to 20 inches and dry weather prevails late in the spring when the wheat crop matures, these varieties would be able to escape the spring drought and hot winds to which were attributed the low yields obtained in this country. Later it was found that the black rust was also responsible for reducing the yields.

As early as 1892, Chassiotis (2),[3] working in Thessalie, the largest wheat-producing district of Greece, analyzed the factors affecting wheat yield and pointed out the need for the introduction of wheat varieties from abroad which "would be more productive, of a better quality, early maturing, and resistant to drought and to lodging."

Yenadios (12) in discussing the advantages of Rieti wheat, especially its earliness and high gluten content, recommends its testing with the hope that by escaping the hot wind which blows usually in May, it might give good results.

Zalokostas (11), testing the Australian wheat Cedar in Yiannina, and Evelpidis (3) the wheat Indian in Patras, report that these wheats present special interest for Greece on account of their earliness.

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[2] Assistant agronomists. The writers wish to thank Prof. Papandreou for making available the material on which this study is based. They are also indebted to Prof. H. H. Love for having read the manuscript and given valuable suggestions.

[3] Figures in parenthesis refer to "Literature Cited," p. 723.

Papandreou (6), reporting results on testing an early Vilmorin wheat resistant to lodging, points out that this wheat is earlier than those of the Greek soft wheats but three to four days later than the hard red wheats grown in eastern Greece. Later, in reporting results on testing certain wheats created by Strampelli and on a very early black oat of Vilmorin, he (7) stresses their value for their earliness and the high yields obtained in the experimental plats of the Superior School of Agriculture in Athens.

Papadakis (8), in discussing problems of developing early varieties and kinds resistant to drought, points out the need for testing early Australian and California wheats. In later publications he (9, 10) analyzes the results of wide experimentation with these early varieties to ascertain their value for northeastern Greece and recommends them for propagation among farmers.

The above-stated opinions have been confirmed lately by the significant results obtained with certain spring wheats introduced from abroad and grown over a large area in this country. On this basis, therefore, it must be considered as a guiding principle that early varieties should be the center of attention of any successful wheat breeding program in eastern Greece.

The next step is to analyze the factor of "earliness" and determine more specifically for southeastern Greece, where the experimental plats of the Superior School of Agriculture are located, (a) what phenological averages should be taken as an index of the yielding capacity of varieties under these conditions; and (b) what are the time limits within which varieties should head and mature in order to avoid the early spring frosts which are so frequent in this part of Greece, and on the other hand, escape the dry weather at the critical period of growth and complete their maturity under the most favorable conditions.

To this end yields have been correlated for a group of varieties over a 4-year period with the number of days from planting to heading, from planting to maturity, and from heading to maturity.

MATERIAL USED

The data on which this study is based include 99 wheat varieties and strains taken out of a large number of varieties and selections which are being tested each year in the experimental plats of the Superior School of Agriculture in Athens. The wheats included in this group were grown every year during a 4-year period, in plats of 4 square meters on the same experimental field, were planted on the same date or within two days, and had a normal growth during the year.

Yield determinations were based on single plats as well as on replicated ones. In 1930–31, 36% of the plats were replicated from two to four times; in 1931–32, 43%; in 1932–33, 36%; and in 1933–34, 14%. Variation in single plats was measured by the variety Gremenia which was used as a check every year. In 1930–31 the standard deviation in percentage of the mean was 33%; in 1931–32, 20%; in 1932–33, 36%; and in 1933–34, 31%. (See Table 2.)

The number of days from planting to heading and from planting to maturity were also considered for each variety. On this basis, the number of days which elapsed between heading and maturity was calculated.

Due to the fact that the varieties were taken at random as far as the degree of earliness was concerned, and since the relative degree of earliness of each case inserted in the correlation tables has a direct influence on each coefficient of correlation, the analysis of the material presented in Table 1 regarding the earliness of each variety, has special interest. Table 1 refers to the time of heading of each variety under the climatic conditions prevailing in Athens.

TABLE 1.—*The distribution of 99 wheat varieties on the basis of time of heading, Athens, Greece.*

Classification	Time of heading	No. of varieties
Very early	Previous to April 18	1
Early	Between April 18 and 28	12
Average	Between April 28 and May 11	53
Late	After May 11	33
Total		99

While the distribution of the 99 wheats given in Table 1 was made on the basis of quite a few years of experience and for a more or less normal year as regards the distribution of rainfall and early spring temperatures, the information given in Table 2 indicates that there is a considerable variation in the time of heading from one year to another for each variety. This variation extends to 16 days for the 4-year period, while the sowing was done within a period of less than a month. This point is illustrated by the curves in Fig. 1, which at the same time show the basis on which the wheats were classified in Table 1. Furthermore, these curves indicate that the variability within the group for each one of the 4 years is very limited, the coefficients of variability ranging from 4.96 to 6.10% for heading and from 2.73 to 3.51% for maturity. It will be observed also from the shape of the four curves that the late-maturing varieties constitute a distinctly separate group which comes to heading in a short period of time, and therefore, renders difficult the distinction between late and very late varieties. Undoubtedly this is due to the dry weather which prevails during May and which hastens the heading of certain very late varieties.

DISCUSSION

In general, the coefficients of correlation given in Table 3 are, with the exception of one instance, very significant as measured by Fisher's method. The negative correlations observed between yield and number of days to heading and number of days to maturing indicate that "earliness" of varieties is of prime importance in obtaining high yields, and further confirm a fact which in the beginning of this paper was considered as an established principle. However, an analysis of the data of the first two columns of Table 3 shows

TABLE 2.—*The lowest, the mean, and the highest value in time of heading, maturity, number of days between heading and maturity, and yield for the four variables, using the standard variety Gremenia as check.*

Year and date of planting	Values	No. of days from sowing to heading	No. of days from sowing to maturity	No. of days between heading and maturity	Yield
1930–31......	Earliest	128 (April 9) Ballila, 290 gr.	168 (May 19) Ballila, 290 gr.	16, Australia, 380 gr.	S. Boyta (April 18 & May 8), 100 gr.
Dec. 2–3, 1930	Mean of all varieties	154 (May 2)	185 (June 5)	30.5	408 gr.
	Latest	171 (May 22) Vilm. 29, 150 gr.	198 (June 16) Vilm. 29, 150 gr.	46 Mentana, 575 gr.	B.X.I.P. (April 30 and May 31), 935 gr.
	Gremenia	143 (April 24)	182 (June 2)	39	Mean of 6 replications, 365±48 gr.
1931–32	Earliest	122 (April 23) Ballila, 2,550 gr.	159 (May 30) Florence, 1,150 gr.	17, Virgilio, 0.870 gr.	Leventis (May 12 and June 10), 270 gr.
Dec. 23, 1931	Mean of all varieties	143.5 (May 14)	170 (June 10)	28	912 gr.
	Latest	160 (May 30) Hyb. Allices, 900 gr.	181 (June 22) Vilm. 23, 1,170 gr.	41, Ballila, 2,550 gr.	Ballila (April 23 and June 3), 2,550 gr.
	Gremenia	138 (May 8)	169 (June 10)	33	Mean of 25 replications, 1,196±49 gr.
1932–33	Earliest	133 (April 11) Ballila, 1,420 gr.	174 (May 22) Mentana, 1,070 gr.	21, Mazolino, 0.250 gr.	Asprostaro (May 13 & June 10), 120 gr.
Nov. 29, 1932	Mean of all varieties	159. 5 (May 7)	191 (June 8)	31.5	510 gr.
	Latest	175 (May 23) Vilm. 27, 570 gr.	207 (June 24) Vilm. 27, 570 gr.	42, Arnaouti, 210 gr.	Ballila (April 12 and May 21), 1,420 gr.
	Gremenia	154 (May 2)	185 (June 2)	31	Mean of 12 replications, 608±64 gr.
1933–34	Earliest	109 (April 12) Ballila 1,920 gr.	148 (May 21) Florence 1,230 gr.	14, Kamboura, 155 gr.	Triminia (May 16 and June 1), 75 gr.
Dec. 24, 1933	Mean of all varieties	130.5 (May 3)	159 (June 1)	29	834 gr.
	Latest	144 (May 17) R. P. Barbu, 130 gr.	173 (June 15) Australia, 1,200 gr.	45, B. P. X. I., 1,910 gr.	Duretranger (May 1 & June 5) 2,230 gr.
	Gremenia	122 (April 25)	155 (May 28)	33	Mean of 13 replications, 1,268±110 gr.

*Standard errors.

that we should distinguish between earliness in heading and earliness in maturity, the former being of much greater importance as an index of the yielding capacity of the varieties than the latter which should be regarded rather as a correlary condition of heading, much depending on weather conditions.

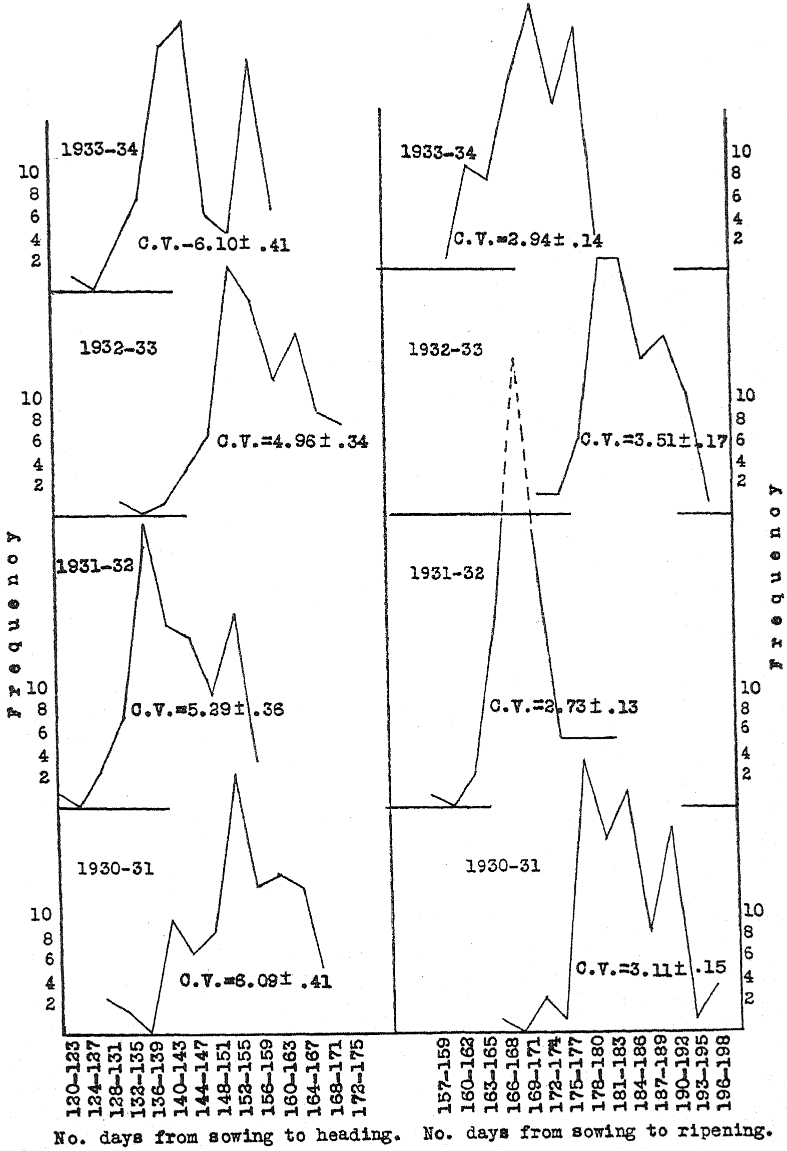

FIG. 1.—Curves showing basis on which wheats were classified in Table 1.

TABLE 3.—*The degree of correlation between yield and number of days from planting to heading and to maturity, and number of days between heading and maturity for a 4-year period.*

Crop years	Correlation coefficient between yield and		
	No. of days to heading	No. of days to maturity	No. of days between heading and maturity
1930–31........	—.471	—.441	+.401
1931–32........	—.726	—.250	+.529
1932–33........	—.371	—.218	+.990
1933–34........	—.357	—.030	+.486

Note: n = 100 and P = 5%. Coefficients above .1946 are significant. (See Fisher's table giving values of correlation coefficients for different levels of significance.)

In 1930–31 a good degree of negative correlation was observed between yield and number of days to maturity due to a combination of exceptional weather conditions—low temperature in March ranging from —1° to —5.6° C, with rainy weather in April and May—which favored the development of black rust to such an extent that all varieties were more or less severely attacked by the disease. Obviously the earlier varieties were attacked by rust in a latter stage of maturity and this explains why the early maturing varieties gave higher yields in 1930–31.

In contrast to the correlation coefficients between yield and number of days to maturity, which fluctuate greatly in the 4-year period, coefficients between yield and number of days to heading are more consistent. The high degree of negative correlation observed in 1931–32 should be regarded as one of the highest coefficients ever attained with the given group of varieties due to the fact that after a rainy March (77.5 mm), the subsequent period up to June was practically dry so that, while there was enough moisture in the soil at the critical period of the earlier heading varieties, the late varieties were severely handicapped by dry weather. On the contrary, in 1933–34, a low degree of correlation was observed between yield and number of days to heading on account of the dry weather which prevailed in March and April (5.4 mm) at the critical period for early varieties, the yields of which were materially reduced, while on the other hand, the rainy, cool weather in May favored the average and some of the late varieties which gave exceptionally good yields. Both these years should be considered as exceptional in so far as the distribution of rainfall is concerned.

According to weather data supplied by Aeginitis (1) for Athens, there have been 5 years out of 46 with a spring as dry as that of 1931–32, and 4 years with a dry April (below 10 mm) and May above normal as in 1933–34. It seems, therefore, that the lowest and highest coefficients observed in the 4-year period between yield and number of days to heading should be regarded as marking practically the limits in the range of these coefficients. Furthermore, the fact that in 17 years out of 46 rainfall in April and May was below normal and that in 9 of these years there was practically no rainfall, with only 11 years with rain above normal at the same period, suggests that in the long run there are greater probabilities of having years with a dry spring, as in 1931–32, and therefore with a high coefficient, than years with a dry April and rainy May as in 1933–34, which resulted in a low coefficient. The distribution of rainfall at Athens during the 4 years of these studies is presented in Table 4.

The significance of earliness in heading is further stressed by the good and constant correlation obtained between yield and number of days from heading to maturity (Table 3) which means that the more the maturity period is extended, the higher the yield obtained. This is obviously another way of saying that the earlier heading varieties will give higher yields, for so long as the maturity period is checked by dry weather it follows that in order to have the longest maturity period heading should start as early as possible. Therefore, the correlation coefficients in columns 2 and 4 of Table 3 indicate to a certain extent the same thing in two different ways.

TABLE 4.—*Distribution of rainfall at Athens with the respective number of rainy days in the 4-year period 1930–34, and during a normal year.**

Crop year	Total rainfall, normal year, mm†	Rainfall, July–Feb., mm	Rainfall by months, mm				
			March	April	May	June	Total for 4 months
1930–31	544.3	403.9	33.2 (8)‡	52.6	34.7	19.9	140.4
1931–32	368.3	275.7	77.5 (13)	12.1 (3)	0.0 (0)	3.4 (2)	92.9
1932–33	286.5	193.1	12.6 (6)	26.4 (10)	30.5 (4)	23.9 (5)	93.4
1933–34	410.2	300.1	60.3 (16)	5.4 (6)	31.6 (12)	12.8 (5)	110.1
Normal year	393.3	290.8	34.3 (10.6)	20.7 (8.5)	19.6 (7.5)	17.2 (4.6)	91.8

*From observations made by the weather office of the Superior School of Agriculture, Athens.
†Given by Aeginitis (1).
‡Figures in parenthesis number of rainy days.

On the basis of the above discussion it seems quite evident that attention should be directed toward obtaining early heading strains and varieties which at the same time will develop a drought resistance complex in order to extend their maturity period as long as possible.

Information given by Aeginitis (1) suggests that varieties can head as early as the middle of March without danger of injury by early spring frosts. According to these data, in 40 years out of 46 minimums of temperature in March ranged between 0° and 10° C and only in 6 years were temperatures below 0 observed. However, field observations indicate that, as a rule, every year the tops of the leaves of early varieties are injured by frosts in March, and in some years, as in 1931 when the frost was so constant, the spikes of early varieties which are beginning to form at that time are injured also. Observations made by Kyriazopoulos (4) in Athens on the minimum temperature on the top of grass throw some light on this problem. He found that the minimum temperatures on the top of grass were, as a rule, lower than the minimums on the surface of the ground, both grassy and barren, and always lower than the respective air minimums. The difference between air minimums and that on the top of the grass ranged from —0.3° to —7.1° C for the 11 days of 1931 during which air minimums below 0° were observed. On March 20, 28, and 29 air minimums were —1.8°, 0.0°, —2.2°, respectively, while the minimums on the top of the grass for the same dates were —6.8°, —0.3°, and —5.6° C. Furthermore, during 1931, temperatures below 0° were observed 50 times on the top of grass. He concludes that these exceptionally low temperatures on the top of the grass cannot be detected through the usual air temperature and soil observations.

These observations, although covering a period of 1 year, conclusively indicate that air and soil temperature minimums cannot be used in deciding up to what time varieties can head without being damaged by frosts, and that data like that given by Kyriazopoulos for a long period of time are needed in order to answer the above question.

The data on hand, as well as field observations to date, suggest that it is not wise to try to obtain varieties heading earlier than Ballila, which heads during the first 10 days of April in Athens, unless these varieties would develop cold resistant qualities at the same time. Thus, it seems that in addition to the need for obtaining varieties which would extend their ripening period as long as possible by developing a drought resistance complex, we must look for varieties which at the same time will be able to resist early spring frosts. Although it has been found that in general resistance to both freezing and drought is due to the same structural and physiological qualities, the experimental work of Martin (5), who found that spring wheats differ relatively little in cold resistance when actively growing at the time the spikes begin to form, indicates that there are not so many possibilities in this field.

SUMMARY

Yields have been correlated for a group of 99 wheat varieties over a 4-year period with the number of days from sowing to heading, from sowing to ripening, and with the number of days which elapsed from heading to ripening. The wheats were sown every year on the same date in plats of 4 square meters on the same experimental field. Actual yields for each case were taken together with their corresponding number of days from sowing to heading and ripening. On this basis the number of days between heading and ripening was also calculated.

In general, a good correlation was found to exist between yield and the three variables confirming the prevailing idea among Greek agriculturalists that "earliness" is of prime importance in obtaining high wheat yields in eastern Greece.

In analyzing the data a sufficiently constant association was found to exist between yield and number of days to heading to indicate

that this phenological average might be taken as an index of the yielding capacity of the variety. The significance of this index was further stressed by the high and consistent positive coefficients of correlation between yield and number of days elapsing from heading to ripening, inasmuch as usually the maturity period is checked by dry weather and in order to have the longest maturity period, as this coefficient indicates, heading should start as early as possible.

Furthermore, with the available data and with field observations to date, it is not wise to try to obtain varieties heading earlier than Ballila, which heads the first 10 days of April in Athens, unless the varieties develop besides a drought-resistant complex which would enable them to extend their ripening period as long as possible and which would at the same time enable them to resist early spring frosts.

LITERATURE CITED

1. AEGINITIS, B. The Climate of Greece. Part I, The Climate of Athens. Athens.
2. CHASSIOTIS, S. The proper selection of wheat seed for increasing the yield. Greek Farming, 66. 1892.
3. EVELPIDES, X. Wheat varieties of the Ahaia district. New Agr., 1919 : 90. 1919.
4. KYRIAZOPOULOS, B. D. Minimums of temperature observed on the top of grass. Min. Acad. Athens, 401–405. 1932.
5. MARTIN, J. F. The cold resistance of Pacific Coast spring wheats at various stages of growth by artificial refrigeration. Jour. Amer. Soc. Agron., 24: 871–880. 1932.
6. PAPANDREOU, S. L. A wheat resistant to lodging. New Agr., 1915 : 77. 1915.
7. ————. The wheats Arditto and Mentana and the black oat. Bul. Attica Chamber of Farmers, August, 1929.
8. PAPADAKIS, I. S. Let us improve our cereals. New Agr., 1923 : 88. 1923.
9. ————. The wheats Camberra, Waratah, and Florence in Greece. Athens. 1927.
10. ————. The introduction of foreign wheats Camberra and Mentana in Greece. Bul. Intern. Assoc. Plant Breeders, March, 1931.
11. ZALOKOSTAS, M. The Australian wheat Cedar. New Agr., 1919 : 178. 1919.
12. YENADIOS, P. A new wheat variety. Greek Farming. 1894 (page 604).

EFFICIENCY OF AMMONIATED SUPERPHOSPHATES FOR COTTON[1]

J. T. Williamson[2]

THE process of using superphosphate as an absorbent for ammonia, although known for many years, was not practiced extensively in the fertilizer industry until about 1928. Its use began commercially when the production of synthetic nitrogen compounds made cheap ammonia available for fertilizers.

The simple process of ammoniation is of considerable economic importance for the several reasons enumerated by Jacob and Ross.[3] One of the most important reasons given was that it afforded a way of using anhydrous ammonia, one of the cheapest forms of nitrogen available to the fertilizer industry. A serious problem of importance to all interested in the production and use of mixed fertilizers was the fact that the addition of ammonia to superphosphate resulted in the formation of less soluble phosphates. Keenan's[4] work showed that superphosphate, carrying 89.4% of the phosphoric acid as mono-calcium phosphate and 10.6% as di-calcium phosphate, on ammoniation to 2% ammonia contained 12.3% of the phosphoric acid as mono-calcium phosphate, 36.4% as di-calcium phosphate, and 51.3% in the form of mono-ammonium phosphate. On increasing the ammonia content to 4%, the superphosphate was found to contain 14.7% di-calcium phosphate, 43.5% tri-calcium phosphate, and 41.8% mono-ammonium phosphate. Ammoniation to 6% ammonia changed the phosphate to 79% tri-calcium and 21% mono-ammonium phosphate.

In order to determine the influence of the less soluble, and supposedly less available phosphates, on the yield of cotton, a considerable number of field experiments were conducted. In these experiments, a study was made of the efficiency of superphosphate, ammoniated superphosphates carrying approximately 2 and 4% nitrogen, and precipitated tri-calcium phosphate. This paper reports averages of the results obtained in Alabama during 1931 to 1934, inclusive.

PROCEDURE

All of the experiments reported were conducted cooperatively with farmers. In this paper the term "experiment" refers to the studies made on one series of plats during a single year. The method of replication employed was to locate a

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[2] Associate Agronomist. The writer wishes to express his appreciation to F. E. Bertram, J. W. Richardson, and J. R. Taylor, Jr., for assistance with the field work in connection with the experiments herein reported.

[3] JACOB, K. D., and ROSS, W. H. Chemical nature and solubility of ammoniated superphosphates and other phosphates. Jour. Amer. Soc. Agron., 23 : 771. 1931.

[4] KEENAN, FRANK G. Reactions occurring during the ammoniation of superphosphates. Jour. Ind. and Eng. Chem., 22 : 1378. 1930.

single series of plats on one farm and repeat the experiment on the same soil series in other communities, or perhaps, in the other counties.

Experiments were conducted on the following soil series: Clarkesville and Dickson soils of the Highland Rim; Decatur and Dewey soils of the Limestone Valleys; Hartsells soils of the Appalachian Plateau; Cecil soils of the Piedmont Plateau; and Norfolk, Kalmia, Ruston, Greenville, Orangeburg, and Cahaba soils of the Coastal Plain.

For convenience in tabulating the data, similar soils have been grouped and each soil group has been named for the soil series on which the majority of the experiments within the group was conducted. The Greenville soil group of the Coastal Plain includes the results of experiments on Greenville, Orangeburg, and Cahaba soils and the Norfolk group of this region includes the results of experiments on Norfolk, Ruston, and Kalmia soils.

RESULTS

A study of the data in Tables 1 and 2 shows that these experiments were conducted on soils which responded well to the applications of phosphoric acid. Only the Greenville soil group failed to produce as much as 200 pounds increase of seed cotton per acre from the use of 60 pounds of phosphoric acid. On the Highland Rim and the Appalachian Plateau increases of 308 and 298 pounds of seed cotton per acre, respectively, resulted from the superphosphate application. In the average of all experiments, superphosphate produced an increase of 241 pounds of seed cotton per acre.

The 2% ammoniated superphosphate produced an average increase of 242 pounds of seed cotton per acre, which is practically the same increase as that obtained from superphosphate. No significant differences in the results with 2% ammoniated superphosphate and the untreated superphosphate were obtained on any soil group unless the 20-pound difference in the increases on the Limestone Valley soils should be so considered.

Four per cent ammoniated superphosphate produced an average increase of 218 pounds of seed cotton per acre. If the increase due to superphosphate is assumed to be 100, the increase due to 4% ammoniated superphosphate is 90. Except on the Greenville soil group where the increase due to phosphoric acid was lowest, 4% ammoniated superphosphate was less effective than untreated superphosphate by amounts varying from 14 to 46 pounds of seed cotton per acre. The 4% ammoniated superphosphate was least effective the first year that these experiments were conducted (1931) and each year thereafter became increasingly effective as compared with superphosphate until 1934 when it gave an average increase practically equal to that of superphosphate. As most of these experiments were conducted on the same areas from year to year, the increase in the effectiveness of the ammoniated superphosphate was probably due to the cumulative effect of the phosphate.

Precipitated tri-calcium phosphate was on the average only 85% as effective as superphosphate. It was equally as effective as 4% ammoniated superphosphate on the Highland Rim, Limestone Valley, Appalachian Plateau, and Piedmont Plateau soils. However, it was

TABLE 1.—*Average yield of seed cotton, using different sources of phosphate on various soil regions of Alabama, 1931–1934, inclusive.*

Plat No.	Fertilizer treatment*	Source of phosphate and kind of supplement	Pounds of seed cotton on						
			Highland Rim, Clarkesville soils, 29 expts.	Limestone Valley, Decatur soils, 33 expts.	Appalachian Plateau, Hartsells soils, 28 expts.	Piedmont Plateau, Cecil soils, 27 expts.	Coastal Plain		Average of all soils, 185 expts.
							Greenville soils, 19 expts.	Norfolk soils, 49 expts.	
1	6–0–4	None	667	983	793	677	828	744	781
2	6–10–4	Superphosphate	948	1,201	1,081	947	926	986	1,021
3	6–10–4	Ammoniated superphos. (2% N)†	943	1,221	1,074	953	932	980	1,022
4	6–10–4	Ammoniated superphos. (4% N)‡	902	1,185	1,054	933	930	960	998
5	6–10–4	Precipitated tri-calcium phos.	903	1,178	1,063	944	877	925	986
6	6–0–4	None	627	1,000	772	709	827	757	782
7	6–10–4	Superphosphate and ground limestone§	1,015	1,252	1,164	1,043	914	1,016	1,074
8	6–10–4	Ammoniated superphos. (4% N)‡ and ground limestone§	943	1,170	1,109	972	898	967	1,014
11	6–0–4	None	626	979	785	668	834	764	776
Average 6–0–4 plats			640	987	783	685	830	755	780

*600 lbs. per acre; nitrogen from ammonium sulfate sufficient to make 6% N; phosphoric acid from source indicated; potash from muriate of potash.

†Actual analysis was 1.53% N, 1931; 2.10% N, 1932; 2.06% N ,1933; 2.00% N, 1934. Average 1.92% N.

‡Actual analysis was 5.40% N, 1931; 4.65% N on Norfolk, Greenville, and Cecil groups and 3.64% N on Hartsells, Decatur, and Clarkesville groups in 1932; 4.01% N, 1933; 4.00% N, 1934. Average 4.40% N.

§Marble dust, 200 lbs. per acre, in 1931; 200 lbs. dolomite per acre in 1932, 1933, and 1934.

TABLE 2.—*Average and relative increases of seed cotton on various soil regions from different sources of phosphate.*

Plat No.	Source of phosphate and kind of supplement*	Highland Rim, Clarkesville soils, 29 expts.	Limestone Valley, Decatur soils, 33 expts.	Appalachian Plateau, Hartsells soils, 28 expts.	Piedmont Plateau, Cecil soils, 27 expts.	Coastal Plain		Average all soils, 185 expts.
						Greenville soils, 19 expts.	Norfolk soils, 49 expts.	
	Increase in Pounds Seed Cotton per Acre							
2	Superphosphate	308	214	298	262	96	231	241
3	Ammoniated superphos. (2% N)†	303	234	291	268	102	225	242
4	Ammoniated superphos. (4% N)‡	262	198	271	248	100	205	218
5	Precipitated tri-calcium phos.	263	191	280	259	47	170	206
7	Superphosphate and ground limestone§	375	265	381	358	84	261	294
8	Ammoniated superphos. (4% N)‡ and ground limestone§	303	183	326	287	68	212	234
	Relative Increase							
2	Superphosphate	100	100	100	100	100	100	100
3	Ammoniated superphos. (2% N)†	98	109	98	102	106	97	100
4	Ammoniated superphos. (4% N)‡	85	93	91	95	104	89	90
5	Precipitated tri-calcium phos.	85	89	94	99	49	74	85
7	Superphosphate and ground limestone§	122	124	128	137	88	113	122
8	Ammoniated superphos. (4% N)‡ and ground limestone§	98	84	109	110	71	92	97

*Fertilizer 600 lbs. per acre of 6–10–4. Nitrogen from ammonium sulfate sufficient to make 6% N; phosphoric acid from source indicated; potash from muriate of potash.

†Actual analysis 1931, 1.53% N; 1932, 2.10% N; 1933, 2.06% N; 1934, 2.00% N. Average 1.92% N.

‡Actual analysis was 5.40% N, 1931; 4.65% N on Norfolk, Greenville, and Cecil groups and 3.64% N on Hartsells, Decatur, and Clarkesville groups in 1932; 4.01% N, 1933; 4.00% N, 1934. Average 4.40% N.

§Marble dust, 200 lbs. per acre, in 1931; 200 lbs. dolomite per acre in 1932, 1933, and 1934.

much less effective than the 4% ammoniated superphosphate on both of the soil groups of the Coastal Plain. Like the 4% ammoniated superphosphate, there was an apparent accumulative effect of this material from year to year, but the results were not so consistent as with the ammoniated phosphate.

Ground limestone applied at the rate of 200 pounds per acre with the superphosphate mixture gave an increase of 53 pounds of seed cotton per acre. However, when used at the same rate with the 4% ammoniated superphosphate mixture, the increase due to the ground limestone was only 16 pounds.

SUMMARY

The average results from 185 experiments with cotton on different soil groups and with various fertilizer treatments are reported and may be summarized as follows:

1. The increases in the yield due to phosphorus were greatest on the Highland Rim and the Appalachian Plateau soil groups and least on the Greenville soil group of the Coastal Plain.

2. The relative increases due to the different sources of phosphorus on all except the Greenville soil group were in accord with the relative increases obtained in the average of all experiments.

3. Using the increase due to superphosphate as a basis, the relative increases due to the different sources of phosphorus in the average of all experiments were as follows:

Superphosphate	100
Ammoniated superphosphate (2% N)	100
Ammoniated superphosphate (4% N)	90
Precipitated tri-calcium phosphate	85

4. Ground limestone used with the complete fertilizer containing superphosphate produced an average increase of 53 pounds of seed cotton per acre; but when used with the complete fertilizer containing 4% ammoniated superphosphate, the increase due to lime was only 16 pounds of seed cotton per acre.

NITRIFICATION OF AMMONIATED PEAT AND OTHER NITROGEN CARRIERS[1]

R. O. E. Davis, R. R. Miller, and Walter Scholl[2]

CONSIDERABLE interest has been exhibited during the last few years in possibilities of preparing fertilizers from humic materials derived from peat, lignite, and coal. The use of such materials has been recommended for the effects produced on the physical condition of soils in improving their moisture relations and aeration and in producing conditions favorable to greater bacterial activity in the soil.

Lieske (7, 8, 9)[3] and Kissel (4, 5) have carried out extensive experiments tending to show the advantages of these materials. On the other hand, Lemmermann (6), while obtaining some favorable results in field trials from ammonium humate prepared from peat, believed the material could not be produced economically enough to warrant its commercial employment. Fuchs, Gargarin, and Kothny (2) made extensive water and pot cultures with humates prepared from brown coal and obtained some specially promising results with some preparations on certain plants, while the same preparations were not so effective with other plants. Their results on the whole were not conclusive. Crowther and Brenchley (1) have carried out parallel pot, field, and nitrification tests of humates prepared from coal which showed close correlation with each other. They concluded that the ammonia in ammonium humate is about as effective as ammonium sulfate and there was some indication that humic material alone supplied a small amount of available nitrogen.

Possibilities for fertilizer use were indicated by Scholl and Davis (12) in the preparation of a somewhat similar material by the treatment of peat with anhydrous ammonia, thereby obtaining a product with an enhanced amount of nitrogen. Investigation of the value of ammoniated peat as fertilizer material has led to experiments in the conversion of the contained nitrogen into nitrate in the soil. It is generally conceded that the rapid formation of nitrate indicates the presence of a form of nitrogen readily available for plants. Other forms of nitrogen than nitrate may be utilized, but the rate of nitrification in the soil furnishes to some degree a comparison of the readily available nitrogen in nitrogen compounds.

TESTS PERFORMED

Nitrification tests were made in several series of experiments, the first over a period of 2 months, the second for 23 weeks, and the remaining for periods of 10 to 13 weeks. The materials used included ammonium sulfate, cottonseed meal,

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[2] Senior Chemist, Assistant Scientific Aid, and Assistant Chemist, respectively. The authors wish to express their appreciation to F. E. Allison for helpful suggestions in arranging the tests, and for assistance rendered by J. R. Adams, J. C. Bryan and S. R. Hoover in carrying out some of the tests.

[3] Figures in parenthesis refer to "Literature Cited," p. 736.

blood, ammoniated peat prepared at 180°C and at 300°C, water-soluble portions and water-insoluble residues from ammoniated peat, raw peat representing the same nitrogen content as the other materials, raw peat of the same total weight as ammoniated peat, a sample with one-third nitrogen as sodium nitrate and two-thirds as the insoluble portion from the ammoniated peat prepared at 180°C, the soluble and insoluble portions from ammoniated dextrose, and similar materials. The ammoniated peat prepared at 180°C, used in the first series of experiments, contained 10.55% nitrogen; and that prepared at 300°C contained 18.50%. In the second series the nitrogen contents were 10.82% and 12.85% for the 180° and 300° treatments, respectively. The same raw peat employed for preparation of the ammoniated samples was used in the experiments on nitrification.

In preparing the water-soluble portion, 100 grams of ammoniated peat were washed successively on a large filter with 50-cc portions of water at 60°C until the leachings amounted to 2 liters. After cooling the solution was made to 2,000 cc and analyzed for the nitrogen content. This solution was used for the nitrification test on the water-soluble nitrogen.

It has been found as described previously (12) that ammoniated peat contains, on an average, about one-fourth of its total nitrogen as water soluble. Approximately 40% of the soluble nitrogen is present as urea, but the compounds making up the remainder of the soluble as well as the insoluble nitrogen are unknown. Investigations in this laboratory (11) have resulted in the separation from ammoniated products by extraction with various solvents of several groups of nitrogen compounds and determination of their amounts. Extracted residues from ammoniated peat and ammoniated dextrose were tested for nitrification.

Dextrose was ammoniated at 180° in a manner similar to peat, but the product obtained was about 65% liquid with an insoluble residue. The solid and liquid portions were separated and the residue washed with water as in the case of ammoniated peat. The residue and liquid portions were employed in nitrification tests. The nitrogen content of solid and liquid portions of ammoniated dextrose was 17.9% and 21.3%, respectively.

The ammonium sulfate, cottonseed meal, and dried blood were commercial materials of fertilizer grade. They were included to furnish known materials for purposes of comparison.

EXPERIMENTAL PROCEDURE

Nitrification tests were carried out in duplicate in the usual way by adding nitrogenous material containing 20 mg of nitrogen to 100 grams of soil. Soils from two locations were employed and contained 35 mg and 70 mg of nitrogen, respectively, per 100 grams of soil. The prepared samples were placed in a dark basement room of almost constant temperature of 30°C.

For the determination of nitrates the whole sample was transferred to a flask with 100 cc of water and shaken 2 hours. After filtering and washing, an aliquot of the solution was taken for determination of nitrate by the phenol disulfonic acid method (10). There are objections to this method under certain conditions where the color may be affected by chlorides or certain organic materials, but for our purposes the method was quite satisfactory.

RESULTS OF EXPERIMENTS

The results obtained in the various tests are summarized in Table 1, in which the conversions to nitrate are expressed as percentage of added nitrogen and of ammonium sulfate conversion as a maximum.

TABLE I.—*Nitrification of ammoniated peat products and other materials.*

Material	Conversion to nitrates	
	From added N %	Relative to $(NH_4)_2SO_4$
$(NH_4)_2SO_4$	85	100
	90	100
	85	100
	80	100
Am. peat, 180°	25	29
	31.1	34.4
Am. peat, 300°	21	25
	13.4	14.8
Am. peat, H_2O insol. 180°	6	7
	17.3	19.1
Am. peat, H_2insol. 300°	7.5	8.3
Am. peat, H_2O sol. 180°	78	92
	82	91
Am. peat, H_2O sol. 300°	82	91
Raw peat	4	5
	0	0
	7	8
Am. peat, H_2O insol. 180°+$NaNO_3$	13.4	14.8
Soil alone	13.4*	—
	18	—
	19.1	—
	16	—
	14.2	—
Am. peat, H_2O insol. act. 80†	10	12.5
Am. peat, H_2O insol. act. 87	11	13.8
Am. peat, H_2O insol. act. 50	12	15.0
Am. lignin 180°	24	30
Am. lignin, H_2O—insol	8	10
Am. starch, 180°	5	6.2
Am. dextrose, H_2O sol.	40	44.3
Am. dextrose, H_2O—insol	8.2	9.1
Am. peat, extracted res.	5.7	7.1
Am. dextrose, extracted res.	3.5	4.4
Cottonseed meal	49	58
	48.5	54
Dried blood	57	67
$MgNH_4PO_4$	93	109
Guanidine carbonate	6	7

*Original nitrogen in the soil converted to nitrate.

†Act. 80, 87, 50 refers to activity of insoluble nitrogen by neutral permanganate (A.O.A.C.) method.

The first series of experiments was continued for 59 days. The conversions to nitrate nitrogen are shown in the curves of Figs. 1 and 2.

The maximum conversion of ammonium sulfate was obtained in 17 days with a conversion of 85% of the added nitrogen. The nitrate formed from the water-soluble portion of ammoniated peat was still increasing on the 59th day with a conversion of 78% of the added nitrogen. Dried blood and cottonseed meal were next in order of nitrate formation, reaching fairly constant values in 17 days, with 57% and 49% conversion as the maximum, respectively. The two whole samples of ammoniated peat gave conversions to nitrate of

25% for the 180° product and 21% for the 300° product. The rates of nitrate formation were different, however, the 180° product reaching a maximum at 26 days and the 300° product at 59 days. The latter gave values slightly below the soil alone up to the 38th day followed by a rather rapid formation of nitrate. The samples of raw peat and of the insoluble residue from ammoniated peat showed small amounts of nitrates slowly formed; raw peat reaching a 4% conversion and the insoluble residue 6% on the 59th day. Compared to ammonium sulfate, the conversion to nitrate of cottonseed meal was practically half as great, and the whole ammoniated peats 25 and 29%.

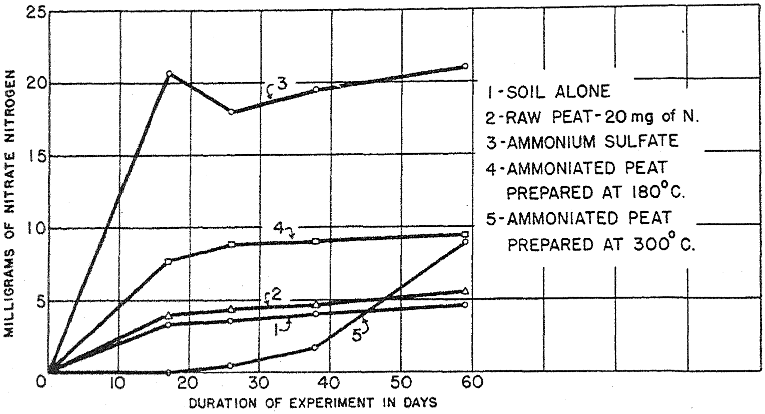

FIG. 1.—Series 1. Nitrification of nitrogenous materials.

The second series contained both soluble and insoluble portions of ammoniated peat, a mixture of sodium nitrate and leached residue, and products from ammoniated dextrose. This series was continued for 23 weeks, the summary of the results are shown in Figs. 3 and 4.

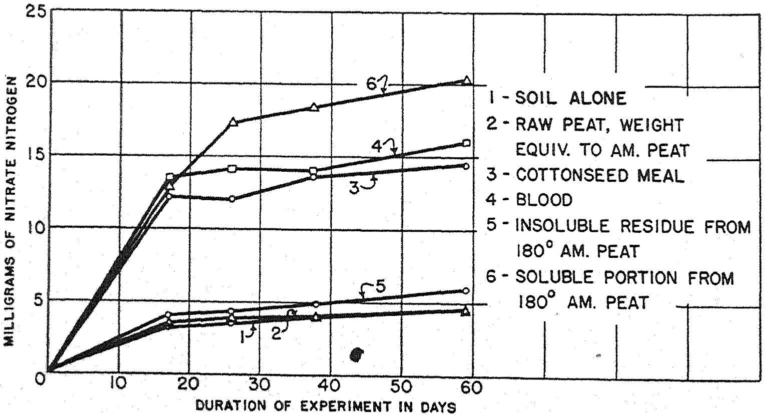

FIG. 2.—Series 1. Nitrification of nitrogenous compounds.

The nitrate maximum was reached in 6 weeks for 300° ammoniated peat at 13.4% conversion, the 300° ammoniated peat residue at 7.5%, the 180° ammoniated peat residue at 17.3%, and the 180° ammoniated peat residue with $NaNO_3$ at 13.4%. In 8 weeks maximum nitrate was shown for raw peat at 7.3% conversion, water-soluble portion of 300° ammoniated peat at 81.7%, 180° ammoniated peat at 31.1% and the soluble portion at 82.2%, and ammoniated dextrose residue at 8.2%. Ammonium sulfate reached maximum nitrification of 90.3% at 11 weeks, and cottonseed meal and water-soluble ammoniated dextrose at 18 weeks with 48.5% and 40.0% conversion, respectively. After the 8th week nitrate decreased in most cases and after the 18th week in all cases. The nitrate found at the end of 2 weeks was below the blank in the case of all fractions of the ammoniated peats prepared at 180° and 300° and of the soluble portion of ammoniated dextrose. With the exception of the dextrose fraction all had risen above the blank in nitrate content after 4 weeks; the dextrose fraction was considerably above the blank after 6 weeks. Included in the tests for comparison were magnesium ammonium sulfate and guanidine carbonate as different types of compounds. The magnesium ammonium phosphate prepared by W. H. Ross and K. C. Beeson of this Bureau, nitrified almost completely. The results from

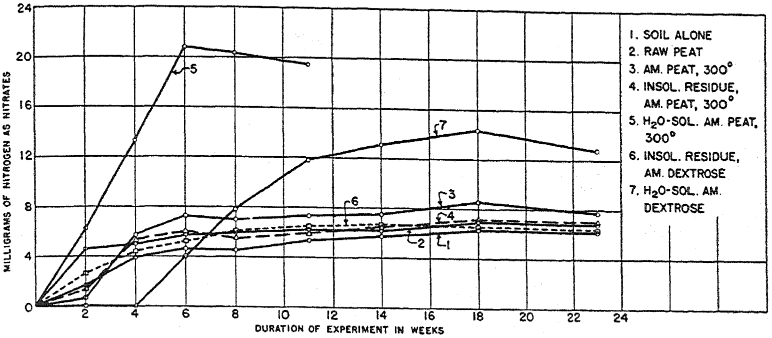

FIG. 3.—Series 2. Nitrification of nitrogenous materials.

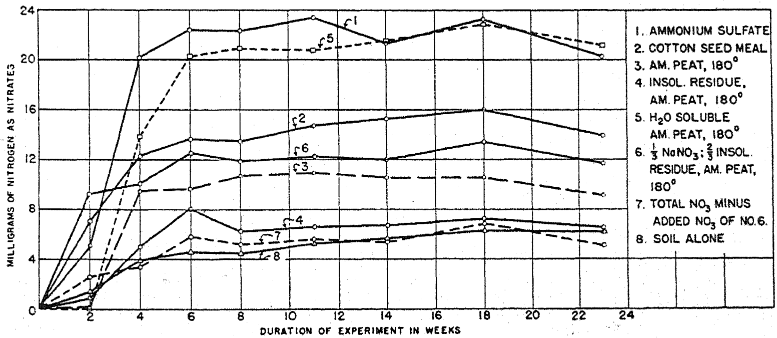

FIG. 4.—Series 2. Nitrification of nitrogenous materials.

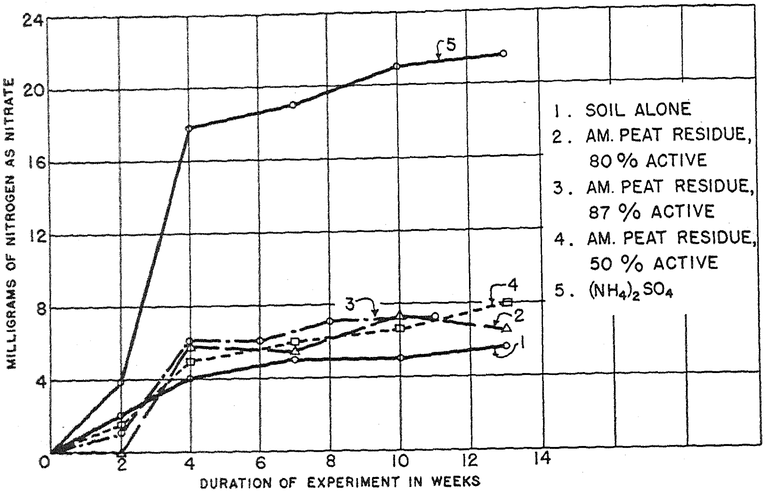

FIG. 5.—Series 3. Nitrification of ammoniated peat insoluble nitrogen of different activities.

guanidine carbonate were considerably lower than those obtained by Jacob, Allison, and Braham (3) for a similar period.

The series including ammoniated starch, ammoniated lignin and its insoluble residue, and the residues from three ammoniated peat samples showing activities by the neutral permanganate method of 50%, 80%, and 87% ran for 13 weeks. The results are summarized in the curves of Figs. 5 and 6 showing the rate and extent of nitrification.

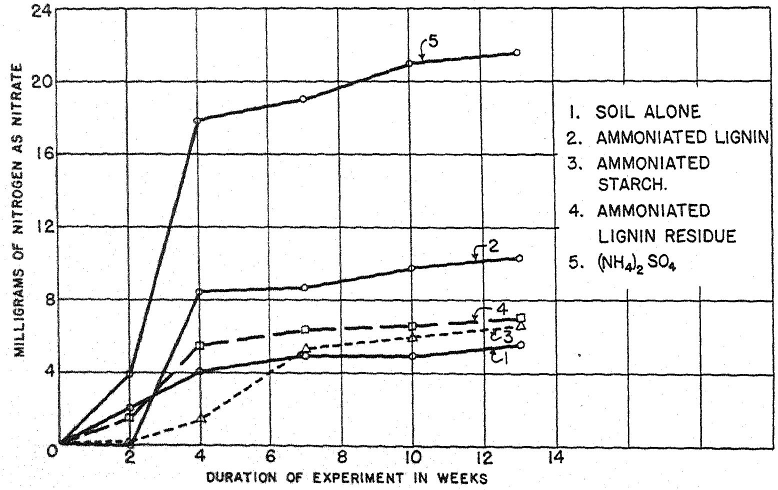

FIG. 6.—Series 3. Nitrification of ammoniated lignin and starch.

The conversion of ammonium sulfate in this series was somewhat lower than usual, reaching a maximum of only 80%. Ammoniated starch was lowest in conversion, 5.5%. Ammoniated lignin gave a 24% conversion and the insoluble lignin residue 8.0%. Ammoniated peat residues of 50%, 80%, and 87% activity gave 12%, 10%, and 11% conversion, respectively.

The fourth series contained only the blank and the residues from ammoniated peat and dextrose obtained from rather drastic extractions with various solvents. These were prepared by L. A. Pinck, L. B. Howard, and G. E. Hilbert of this laboratory (11). In the case of ammoniated peat, extractions were made successively with ether, water, alcohol, 2% and 1:1 hydrochloric acid, and the residue still contained 47% of the original nitrogen. Ammoniated dextrose received the same treatment, except extraction with 2% HCl, and the residue contained 38% of the original nitrogen. The extracted ammoniated peat gave a slow nitrification to about 6% conversion, while the extracted ammoniated dextrose showed a slightly increased nitrification over the blank at the end of the experiment (Fig. 7).

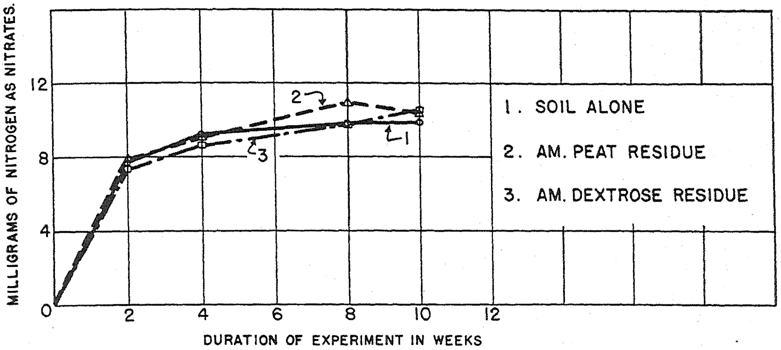

FIG. 7.—Series 4. Nitrification of residues from ammoniated peat and ammoniated dextrose after extended extraction.

The percentage conversion of soil nitrogen to nitrate in the different series of tests varied from 13 to 19. One soil employed in four tests contained 0.035% nitrogen and the other soil used in one test contained 0.07% nitrogen. The average maximum conversion of one soil amounted to 16.8% of the total original nitrogen and the maximum conversion in the other soil was 14.2%, or 16.3% for a general average.

SUMMARY

The nitrification of ammoniated products was used as an indicator of the ease of attack of the materials by bacterial action. Nitrification of ammoniated peat prepared at 180° and at 300° arrived at approximately the same maximum value in one series, of about 24% conversion to nitrates. In another series with different samples the 180° sample showed 31% conversion and the 300° sample gave only 13.4%. In both cases the nitrification of the 300° material was longer in starting and the rate was slower than with the 180° material, indicating that the higher temperature had produced some effect that retarded the action of the bacteria.

Separation of the ammoniated peat into water-soluble and water-insoluble portions and subsequent nitrification tests showed that the water-soluble nitrogen compounds in both the 180° and 300° material were quite easily nitrified. The nitrification curve for this portion follows very closely that for ammonium sulfate, and the limited number of experiments indicates that the extent of nitrification is about the same as with ammonium sulfate. The soluble portion from ammoniated dextrose gave a maximum conversion of 40% after 18 weeks.

The leached residues from ammoniated peat left after extracting the water-soluble portion gave somewhat varying results, from 6 to 17% conversion to nitrate. Ammoniated lignin and its leached residue gave nitrification values corresponding closely to those of ammoniated peat. The whole ammoniated starch gave about the same value as raw peat and somewhat less than the water-leached residues from ammoniated peat. The water-leached residue from ammoniated dextrose gave 8.2% of the total nitrogen as nitrate after 8 weeks. Ammoniated peat residue and ammoniated dextrose residue from exhaustive extractions with several solvents were nitrified somewhat more in each case than raw peat. Ammoniated peat water-insoluble residue with sodium nitrate added gave a nitrification value of 13.4% after 6 weeks as contrasted with the 17% for a similar residue alone tested in the same series.

Three ammoniated peat water-insoluble residues, with active nitrogen of 50%, 80%, and 87% according to the neutral permanganate method, all gave low conversion to nitrate of approximately the same values, 12, 10, and 11%, respectively.

Magnesium ammonium phosphate nitrified at about the same rate as ammonium sulfate. Guanidine carbonate after 12 weeks had a conversion value of only 6%.

Soil nitrogen alone, as shown by the check runs, attained average conversion to nitrate of 16.3%, which is about equal to that of the leached residues from ammoniated peat and somewhat greater than the raw peat. This would indicate that the insoluble nitrogen of ammoniated peat becomes available as nitrate at about the rate of the nitrogen in the natural occurring soil organic matter.

LITERATURE CITED

1. CROWTHER, E. M., and BRENCHLEY, W. E. Fertilizing value and nitrifiability of humic materials prepared from coal. Jour. Agr. Sci., 24 : 156. 1934.
2. FUCHS, W., GAGARIN, R., and KOTHNY, H. The influence of brown coal and products from brown coal in increasing plant production. Biochem. Zeitschr., 259 : 85. 1933.
3. JACOB, K. D., ALLISON, F. E., and BRAHAM, J. M. Chemical and biological studies with cyanamide and some of its transformation products. Jour. Agr. Res., 28 : 37. 1924.
4. KISSEL, A. Study of the action of brown coal on plants, I. Brennstoff-Chemie, 11 : 257. 1930.
5. ——————. Study of the action of brown coal on plants, II. Brennstoff-Chemie, 12 : 101. 1931.

6. Lemmermann, O. Value of brown coal and some so-called humus fertilizers. Zeitschr. Pflanz. Düng., 30A : 1. 1933.
7. Lieske, R. Brown coal as fertilizer. Brennstoff-Chemie, 12 : 81. 1931.
8. ————. New experiments on fertilization with coal. Brennstoff-Chemie, 12 : 426. 1931.
9. ————. New investigation on action of coal as fertilizer. Angew. Chem., 45 : 121. 1932.
10. Assoc. Official Agr. Chemists. Methods of Analysis. Ed. 3. 1931. (Page 405).
11. Pinck, L. A., Howard, L. B., and Hilbert, G. E. Nitrogenous composition of ammoniated peat and related products. Ind. Eng. Chem., 27 : 440. 1935.
12. Scholl, W., and Davis, R. O. E. Ammoniation of peat for fertilizers. Ind. Eng. Chem., 25 : 1074. 1933.

THE CLAY RATIO AS A CRITERION OF SUSCEPTIBILITY OF SOILS TO EROSION[1]

GEORGE JOHN BOUYOUCOS[2]

CONSIDERABLE work is being done to discover principles governing and methods of predicting and distinguishing between erosive and non-erosive soils. The terms erosive and non-erosive as applied to soils are only relative for there is no absolutely non-erosive soil; under certain conditions, all soils will erode. But all factors being equal, save the soil factor, it is true that some soils erode much more readily than others. There is no doubt that there is a fundamental principle producing this difference and the problem is, of course, to discover this principle.

Middleton and his associates (1, 2, 3)[3] have done most excellent, extensive, and thorough study on the physical and chemical properties of soil which might influence soil erosion. As a result of those studies, Middleton has proposed the erosion ratio as the best single criterion of erosion. This erosion ratio is obtained by dividing the dispersion ratio by the ratio of colloid to moisture equivalent. The dispersion ratio is obtained by dividing the suspension percentage by the total percentage of silt and clay in the soil and multiplying by 100.

In studying the phenomena of slaking (4), the ultimate structure of soils (5), and the relative dispersibility of soils (6), and in making a mechanical analysis of the aggregate structure of soils (7), it was strongly impressed upon the writer that probably the major and fundamental principle governing and underlying the relative erosiveness of soils is the relation between the content of total sand plus silt and the total clay content. The researches cited above, together with those of other investigators (8), as well as practical experience, make common knowledge of the fact that the clay, together with the colloidal humus, tends to bind and cement soil particles into aggregates. It is on account of this binding and cementing effect that it is difficult to disperse soils, many of which require the application of enormous external energy to be dispersed (9).

With the above facts and conceptions in mind, the accuracy of the ratio of $\frac{\text{Sand} + \text{Silt}}{\text{Clay}}$ as an index of erosiveness of soils was put to a test on a large number of soils which are considered to be erosive and non-erosive. The preliminary results obtained seemed to show that the value of this ratio correlates with the erosiveness of soils. To put this method to a more critical and thorough test, it was decided to apply it on the various soils which Middleton and his associates of the U. S. Bureau of Chemistry and Soils have studied in connection with the problem of soil erosion by taking the reported

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[3] Figures in parenthesis refer to "Literature Cited," p. 741.

mechanical analysis of these soils and working out their $\frac{\text{Sand + Silt}}{\text{Clay}}$ ratio and then comparing this ratio with the erosion ratio which Middleton has proposed as the best single criterion of erosion.

In Table 1 are presented the data on the $\frac{\text{Sand + Silt}}{\text{Clay}}$ ratio which the writer has calculated from the published reports of the U. S. Bureau of Chemistry and Soils. This $\frac{\text{Sand + Silt}}{\text{Clay}}$ ratio will be designated hereafter for convenience as the clay ratio. For purpose of comparison, the erosion ratio which Middleton worked out on the same soils is also presented in Table 1.

TABLE 1.—*Comparison between the clay ratio and the erosion ratio in indicating the relative susceptibility of soils to erosion.*

Depth in inches	Clay per cent content	Clay ratio	Erosion ratio	Depth in inches	Clay per cent content	Clay ratio	Erosion ratio
Nipee Clay							
0–12	47.1	1.12	2.9	12–24	62.5	0.76	2.2
Aikin Silty Clay							
0–20	59.5	0.679	8.7	20–40	65.9	0.517	6.9
Davidson Clay Loam							
0–9	23.8	3.02	12.2	36–60	50.3	0.972	4.3
9–36	60.4	0.60	3.7	60–	29.6	2.36	7.7
Nacogdoches Fine Sandy Loam							
0–8	18.0	4.32	21.7	40–66	34.3	1.91	6.5
8–18	48.4	1.04	6.9	66–72	34.0	1.64	6.2
18–40	38.9	1.56	7.7				
Cecil Fine Sandy Loam							
0–6	25.3	2.86	25.8	6–24	58.6	0.701	6.0
Miles Clay Loam							
0–8	34.0	1.86	21.9	—	—	—	—
Houston Black Clay							
0–3	60.4	0.601	8.1	24–36	61.8	0.602	4.6
14–20	64.1	0.537	3.7	36–50	54.6	0.820	7.8
Colby Silty Clay Loam							
0–10	34.0	1.85	13.0	33–47	38.2	1.56	19.8
10–20	38.0	1.59	8.8	47–60	38.3	1.60	29.5
20–33	38.7	1.57	15.7	60–72	35.7	1.79	30.0
Marshall Silt Loam							
0–13	35.3	1.72	14.2	24–45	33.8	1.86	16.1
13–24	39.4	1.47	6.4	45–71	26.5	2.73	34.5
Palouse Silt Loam							
0–20	27.5	2.56	19.4	33–62	35.4	1.81	16.6
20–33	37.5	1.64	12.7	62–75	29.8	2.35	24.0
Iredel Loam							
0–5	16.4	4.55	24.2	10–20	63.1	0.56	15.0
5–10	16.4	5.05	15.7	20–27	35.2	1.80	22.8
Vernon Fine Sandy Loam							
0–3	8.0	11.2	30.2	10–27	27.0	2.66	13.8
3–10	12.0	7.24	19.0	27–58	32.2	2.08	24.7

TABLE 1.—*Continued.*

Depth in inches	Clay per cent content	Clay ratio	Erosion ratio	Depth in inches	Clay per cent content	Clay ratio	Erosion ratio
Kirvin Fine Sandy Loam							
0–12	8.5	10.3	50.2	51–63	35.4	1.820	10.7
12–24	60.9	0.611	7.2	63–75	9.2	9.82	16.7
24–51	53.4	0.870	7.1	—	—	—	—
Memphis Silt Loam							
0–8	13.4	6.46	65.2	8–28	30–8	2.24	23.3
Orangebury Fine Sandy Loam							
0–16	9.9	9.09	50.9	72–96	16.2	5.11	22.4
16–72	23.0	3.35	12.4	—	—	—	—
Clinton Silt Loam							
0–8	19.1	4.02	57.7	32–44	22.4	3.44	41.7
8–20	24.3	3.09	31.0	44–60	23.2	3.34	24.3
20–32	27.0	2.67	35.5	—	—	—	—
Shelby Loam							
0–7	24.3	3.01	37.4	24–36	41.7	1.30	24.4
7–24	42.5	1.31	22.3	—	—	—	—
Muskingum Silt Loam							
0–7	28.4	2.42	42.1	25–46	28.3	2.38	41.9
8–18	37.1	1.62	19.9	47–72	30.4	2.24	59.6
18–24	34.8	1.75	23.1	—	—	—	—

An examination of the general data presented in Table 1 reveals the fact that the clay ratio varies greatly in the different soils, ranging from 0.517 to 11.2. It is smallest in soils which are considered to be non-erosive, such as the Nipe clay, Division clay loam, Aikin silty clay loam, etc., and greatest in soils which are considered to be very erosive, such as the Kirvin fine sandy loam, Clinton silt loam, Vernon fine sandy loam, Shelby loam, etc. Stickiness and cementing tend to produce the same effect.

By comparing the clay ratio with the erosion ratio, it is seen that, with few exceptions, both ratios tend to run parallel in the same soils and they both tend to indicate about the same thing in regard to the possible behavior of soils towards erosion. This general agreement between these two ratios suggests the possibility that the clay ratio might be employed as a criterion of erosion as well as the erosion ratio. Where the two ratios disagree strongly, it cannot be said at present which one is the more nearly correct. This will have to be proved by future investigations and observations.

As is well recognized, field soil erosion is influenced by a great number of factors. The clay ratio and the erosion ratio aim to take into account only the soil factor and to indicate to what relative degree the various soils would be susceptible to erosion under the same conditions. On this basis and understanding, these two ratios should be of value and help in examining soils as to their possible susceptibility to erosion. If by further studies and observations it is proved that the clay ratio is as good or better a single criterion of erosion as the erosion ratio, then the clay ratio should be more desirable to use for the following reasons: (a) It is based upon logical and scientific principles; and (b) it is simple and rapid to obtain, being completed in about an hour with very little effort (9), while it requires several days to obtain the erosion ratio which involves the extraction of the soil colloids, the determination of vapor adsorption, moisture equivalent, mechanical analyses, and dispersion.

SUMMARY

The $\frac{\text{Sand} + \text{Silt}}{\text{Clay}}$ ratio in soils is suggested in this paper as a possible criterion of judging the relative susceptibility of soils to erosion.

This ratio is designated as the clay ratio. It was compared with the erosion ratio by using the same soils and the same mechanical analyses of these soils as reported by the U. S. Bureau of Chemistry and Soils. The comparison shows that with few exceptions the two ratios agree fairly well in indicating the general susceptibility of soils to erosion.

LITERATURE CITED

1. MIDDLETON, H. E. The properties of soils which influence erosion. U. S. D. A. Tech. Bul. 178. 1930.
2. ————, SLATER, C. S., and BYERS, H. G. Physical and chemical characteristics of the soils from the erosion experiment stations. U. S. D. A. Tech. Bul. 316. 1932.
3. ————, ————, ————. The physical and chemical characteristics of the soils from the erosion experiment stations—second report. U. S. D. A. Tech. Bul. 430. 1934.
4. BOUYOUCOS, G. J. Texture and structure of soils as influenced by chemical agents. Jour. Amer. Soc. Agron., 19 : 788–797. 1927.
5. ————. The ultimate structure of soils. Soil Science, 28 : 27–37. 1927.
6. ————. The relative dispersibility of soils. In press.
7. ————. Making mechanical analysis of the aggregate structure of soils.
8. BAVER, L. D. Factors contributing to the genesis of soil micro-structure. Amer. Soil Survey Assoc. Bul., 16 : 55–56. 1935.
9. BOUYOUCOS, G. J. 1934. A comparison between the pipette method and the hydrometer method for making mechanical analysis of soils. Soil Science, 38 : 335–343. 1934.

THE TEMPORARY INJURIOUS EFFECT OF EXCESSIVE LIMING OF ACID SOILS AND ITS RELATION TO THE PHOSPHATE NUTRITION OF PLANTS[1]

W. H. PIERRE AND G. M. BROWNING[2]

IT has been well established that the use of excessive amounts of lime on certain soils may cause detrimental effects on plant growth, at least temporarily. These detrimental effects, which shall be referred to in this paper as "overliming injury", have in some cases been characterized by a chlorotic condition of the plant and have been found to be caused by a deficiency in the soil of soluble manganese (8, 20, 25, 36),[3] or of iron (6, 9, 37). In other investigations, however, chlorosis has not necessarily accompanied decreased yields (12, 21, 22, 29), and the cause for the overliming injury has not been well established. There is some evidence that excessive liming may result in decreasing the availability of soil potassium (3, 4, 17). It has also been found that liming often decreases the efficiency of the less available phosphate fertilizers, such as bone meal and rock phosphate (10, 31, 32). On the other hand, there is considerable evidence that liming increases phosphate solubility in soils (7, 11, 24, 27, 35), although there are some conflicting data on this point (1, 2, 12, 14).

Midgely (21) has reviewed the literature on the general subject of overliming injury and has studied the possible causes of this condition on overlimed Vermont soils. He found that large additions of organic matter or of calcium silicate were effective in reducing the injury and concluded that neither high pH, the lack of available nutrients, nor the accumulation of nitrites could explain the injury, but that the accumulation of large amounts of calcium salts was probably a contributing factor. In a recent paper published since the present investigation was completed, Midgely and Weisner (22) reported beneficial effects from additions of large amounts of superphosphate; but since they obtained severe injury with flax in the early seedling stages of growth, they concluded that, "the severe injury is not to be attributed to insufficiency of available plant nutrients but rather to some toxic condition, since the nutrients already present in the seeds should provide for a fairly good growth."

The problem of overliming injury has been under investigation at the West Virginia Experiment Station for several years, and it has been found that a temporary decreased growth of crop may result on some soils even when the reaction is considerably below pH 7.0.

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[3] Figures in parenthesis refer to "Literature Cited," p. 757.

In 1930, pastures to which ground limestone was added at the rate of approximately 1.5 tons per acre or in amounts calculated to bring the surface 3 inches of soil to pH 6.0, showed poorer growth than where no lime was used. In the same year alfalfa grown in large tile containers in the field yielded 29% less where the soil was limed to pH 7.2 than where it was limed to pH 6.0. No depression in growth, however, was obtained after the first year. These results have been confirmed by other field observations and by more thorough tests conducted in the greenhouse; and, as shall be seen by the following experiments, the injurious effects of overliming have been found to be associated with a disturbed phosphate nutrition of the plants.

EXPERIMENT I. STUDIES OF GROWTH OF ALFALFA ON SOILS LIMED TO DIFFERENT pH VALUES IN THE GREENHOUSE

In the fall of 1929 nine bulk samples of soils varying in pH from 4.4 to 5.6 were brought to the greenhouse from different sections of the state for a study of the effect of varying degrees of soil acidity on the growth of alfalfa. Each soil was screened, thoroughly mixed, and definite amounts placed in 2-gallon glazed, earthenware pots. Precipitated calcium carbonate was added to bring duplicate pots of each soil to different pH values. In the case of four of the soils which had original pH values above 5.0 (Nos. 504, 505, 509, and 510) one of the treatments consisted of sulfuric acid. After remaining at approximately optimum moisture content for 5 months, all pots were fertilized with muriate of potash at the rate of 100 pounds per acre and monocalcium phosphate at a rate equivalent to 100 pounds P_2O_5 per acre.

Since the detailed results of this experiment will be reported elsewhere, only the more pertinent data will be presented here. Fig. 1 gives the total yields from the three cuttings obtained in 1930. It will be noted that, with one exception, all soils gave considerably lower yields when limed to pH values slightly above 7.0 than where limed to lower pH values, the average decrease in yield being 46%. In most cases the decreased yield from high amounts of lime was considerably more pronounced for the first than for the second and third cuttings. This was especially true where overliming injury was obtained with the first cutting on soils limed to pH values slightly below 7.0. Thus, of the seven soils which were brought to pH values between 6.5 and 7.0, six showed overliming injury at such reactions with the first cutting but only two of the soils did so with the third cutting. When limed to pH values slightly above 7.0, eight of the nine soils continued to show overliming injury with the second and third cuttings.

After removing the third cutting the soils were allowed to remain dry for approximately 6 months after which time they were refertilized as in 1930 and reseeded to alfalfa. The total yields of the three cuttings are shown in Fig. 2. The point of special interest is that with five of the soils the yields were highest at the highest pH values, and that with the other soils the overliming injury at high pH values was much less than in 1930.

No indication was obtained in this experiment as to the immediate cause of the overliming injury. In view of later results, however, it

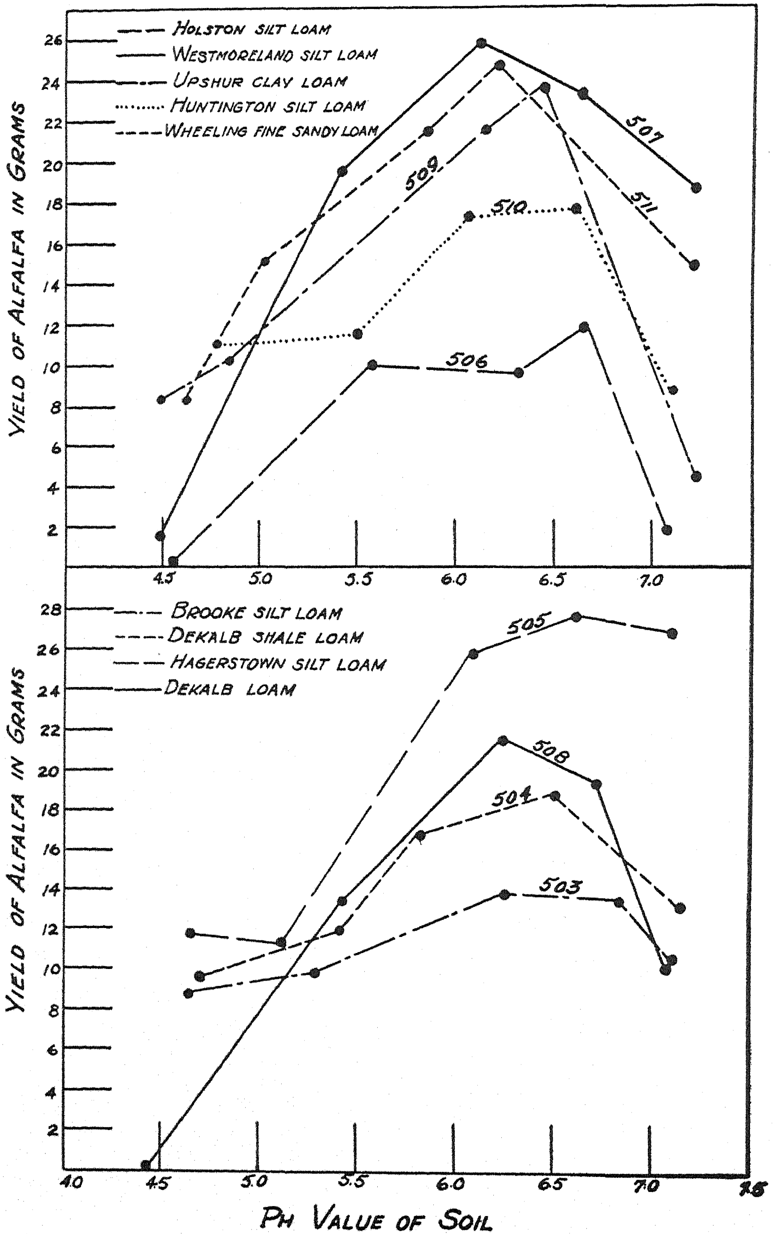

FIG. 1.—The relationship between yield of alfalfa and pH value of soils during the first year after liming (1930).

might be mentioned that the soil with which no injurious effects were obtained from excessive liming, the Hagerstown silt loam, is the most productive soil of the group and the only one which showed no response to phosphorus fertilization. The plants injured from the ex-

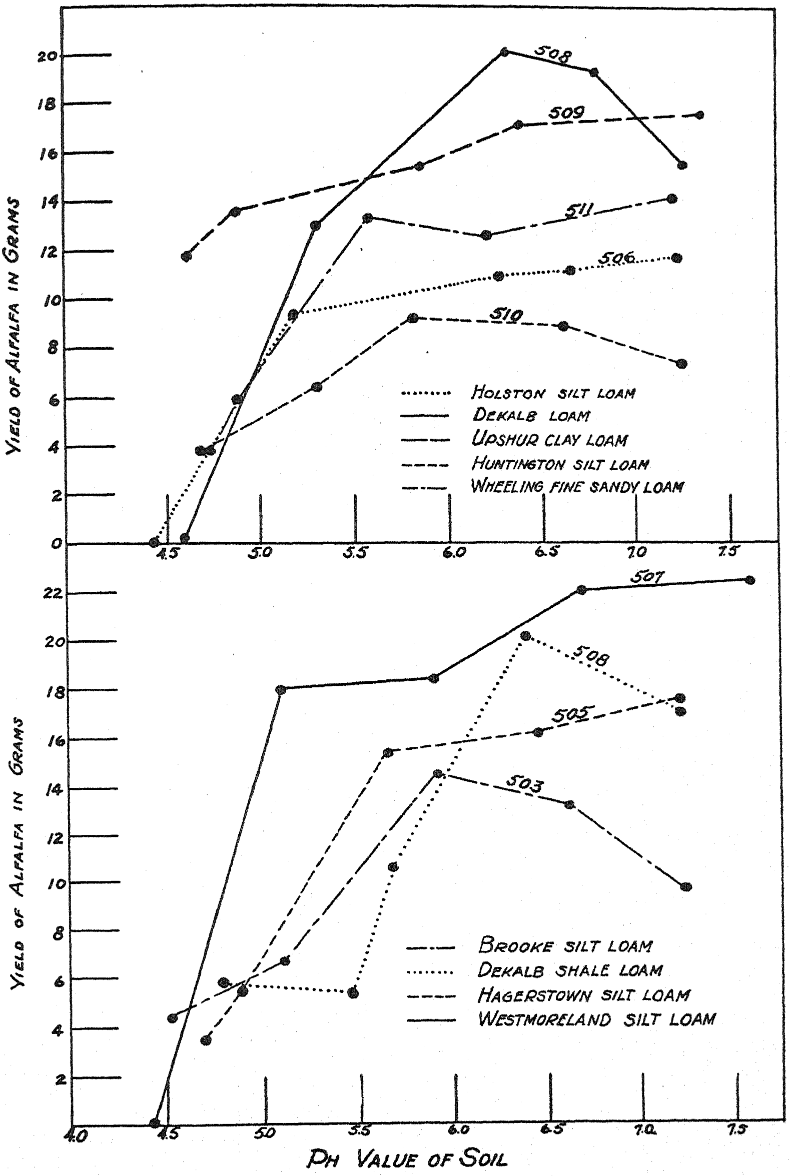

FIG. 2.—The relationship between yield of alfalfa and pH value of soils during the second year after liming (1931).

cessive liming of the soils were stunted and telescoped in appearance. They were not chlorotic, however, but during the latter stages of growth were actually darker green in color than the normal plants.

The results of this experiment emphasize two points, first, that overliming injury can be obtained on many acid soils of West Virginia; and second, that the injury is of a temporary nature. The latter is in agreement with the results of Midgely (21) and Scarseth and Tidmore (29).

EXPERIMENT II. STUDIES OF DIFFERENT SOIL TREATMENTS IN OVERCOMING LIMING INJURY TO CORN IN 1932

Although the injury from excessive liming with alfalfa was not accompanied by chlorosis, it seemed desirable to study the possible beneficial effect of various elements the lack of which had previously been found to be associated with the chlorotic type of liming injury. A large sample of Dekalb loam of approximately pH 4.5 was brought to the greenhouse, thoroughly mixed, screened, and 7,000-gram portions of the dry soil placed in 28 2-gallon pots. To all pots except six, calcium carbonate or different mixtures of calcium and magnesium carbonate were added in sufficient amounts to bring the soil to pH 7.5. Two pots remained unlimed, two were limed with calcium carbonate to pH 6.5, and the other two with equivalent amounts of calcium and magnesium carbonate to pH 6.5. After liming, the soils were kept at approximately optimum moisture content for 6 weeks, after which time they were fertilized and planted to corn.

The fertilization consisted of a uniform application to all pots of nitrate of soda, superphosphate, and muriate of potash at the rates of 400, 500, and 100 pounds per acre, respectively. In addition, certain pots which had been limed to pH 7.5 with calcium carbonate received one of the following treatments, expressed in pounds per acre: 500 pounds KCl; 100 pounds $MnSO_4$; 500 pounds KCl + 100 pounds $MnSO_4$; 50 pounds iron as $FeSO_4$; 50 pounds iron as iron humate prepared from coal; and humic acid in amounts equivalent to the humic acid found in iron humate.

Between 2 and 3 weeks after planting the corn the leaves of most of the plants from the limed pots started to turn pale green to slightly purplish in color. This was true with soils limed to pH 6.5 as well as with those limed to pH 7.5, except where a mixture of calcium and magnesium carbonate had been added. Thereafter, the injury gradually became more pronounced and the leaves on many plants became distinctly purplish in color. The plants on the acid, unlimed soil had a chlorotic appearance characteristic of acidity injury. All plants were harvested after 5 weeks and their dry weights determined. At pH 6.5 a mixture of equivalent amounts of calcium carbonate and magnesium carbonate gave 9.6 grams of oven-dry material as compared to 7.3 grams where calcium alone was used. When limed to pH 7.5 the substitution of one-fourth, one-half, and three-fourths of the calcium carbonate with an equivalent amount of magnesium carbonate resulted in a yield of 8.1, 6.5, and 4.4 grams, respectively, as compared to 6.3 grams where calcium carbonate alone was used.

The yield data also substantiated the observations made during growth that large amounts of potassium chloride, or $MnSO_4$, ferric humate, or humic acid had no effect in reducing liming injury.

After removing the corn crop, the soil in all pots was refertilized with superphosphate at the rate of 500 pounds per acre and the pots seeded to alfalfa. Regardless of treatment the alfalfa made only fair growth where the soil was limed to pH 6.5 and very poor growth when limed to pH 7.5. The plants were therefore removed after 5 weeks.

Since the corn plants had shown a definite purplish color characacteristic of phosphate deficiency, it seemed desirable to continue the study on this soil by giving the pots additional differential treatment, particularly with regard to phosphorus. The soil cultures which had been limed to pH 7.5 with calcium carbonate and had received differential treatment were thoroughly mixed together, then placed back in the pots and given the treatments shown in Table 1. Corn was planted on July 9.

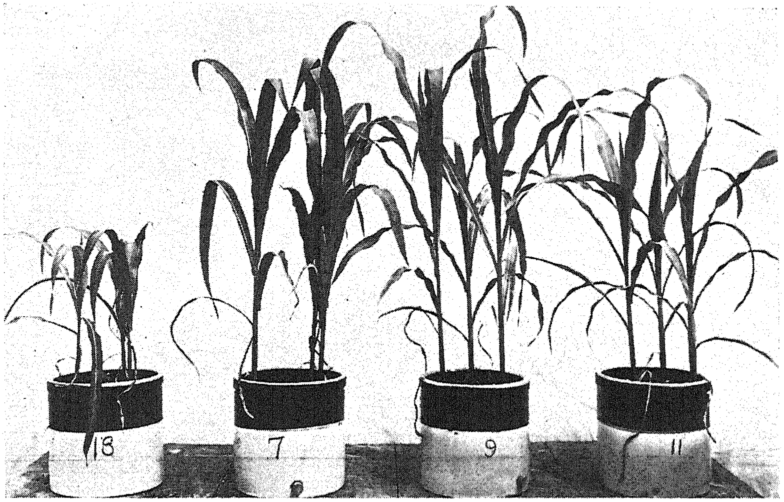

FIG. 3.—The effect of silica gel and of phosphate fertilizers on overliming injury to corn 32 days after planting. Pot No. 18, check, 19.0 grams corn; No. 7, silica gel, 38.8 grams corn; No. 9, additional phosphorus as $CaH_4(PO_4)_2$, 37.0 grams corn; and No. 11, additional phosphate as KH_2PO_4, 37.9 grams corn.

After about 2 weeks the plants began to show slight differences in appearance and growth and within the following 2 weeks these differences became very pronounced. Where no differential treatment was applied or where potassium or magnesium sulfate was added, the plants made very poor growth and the leaves turned a purplish color, characteristic of phosphate starvation. On the other hand, the plants grown on soil receiving silica gel or large amounts of calcium or potassium phosphate made good growth (Fig. 3) and

TABLE 1.—*The yield of corn and the solubility of PO_4 in Dekalb loam (soil No. 609) limed to pH 7.5 and receiving different treatments.*

Pot Nos.	Differential treatments in lbs. per acre	Average yield of corn (oven-dry weight), grams	Inorganic PO_4		Available PO_4 (Truog method), p.p.m.
			Water extract (1:5 soil basis), p.p.m.	Soil solution, p.p.m.	
1–2	Check (no lime)	23.5	0.37	0.13	94
17–18	None	19.0	0.65	0.32	128
7–8	4,000 lbs. silica gel	38.8	1.21	0.48	127
9–10	200 lbs. P_2O_5 as $CaH_4(PO_4)_2$	37.0	1.17	0.37	254
11–12	200 lbs. P_2O_5 as KH_2PO_4	37.9	1.22	0.52	215
13–14	K_2SO_4*	22.7	0.60	—	138
15–16	$MgSO_4$*	20.8	0.63	—	140

*K_2SO_4 was applied at such a rate as to add the same amount of potassium as was added in pots 11 and 12. $MgSO_4$ was added at such a rate as to add the same amount of sulfur as in pots 13 and 14.

had normal green color. Table 1 gives the yields of corn harvested on September 2, as well as the concentration of inorganic phosphate in the displaced soil solution (5, 23) and soil extract (23, 26), and the acid-soluble phosphate by the Truog (33) method of samples taken after the removal of corn. These data show that 4,000 pounds of silica gel per acre and phosphate fertilizers equivalent to 200 pounds of P_2O_5 per acre practically doubled the phosphate concentration in the soil extract, and also doubled the yields of corn.

The remaining pots of soil from the original series were also continued and cropped similarly to those just described. The additional fertilizer treatments, the yield of corn, the concentration of water-soluble phosphate, and the phosphate in the displaced soil solution are given in Table 2. The data show that the soil limed to pH 6.5 with equivalent amounts of calcium and magnesium carbonate gave higher yields than where calcium carbonate alone was used. Likewise, the addition of sodium phosphate to the soil limed with only calcium carbonate decidedly increased the yield. When limed to pH 7.5 the yields were increased where the proportion of magnesium to calcium carbonate was increased, even though the pH was slightly higher where the larger amounts of magnesium carbonate were used. Likewise, the water-soluble phosphorus was increased. When three-fourths of the calcium carbonate was replaced by magnesium carbonate, the phosphorus was approximately doubled in the soil extract and tripled in the soil solution. It is thus evident from the data presented in Tables 1 and 2 that treatments which increased the soluble phosphate in the soil overcame or tended to overcome the liming injury, regardless of whether the treatment consisted of additions of large amounts of phosphate fertilizer, of silica gel, or of substitution of part of the calcium carbonate by magnesium carbonate. Sodium phosphate, however, was not beneficial at high pH values, even though it increased the water-soluble phosphate. Although the reason for this is not clear, it is probable that the sodium was either directly or indirectly toxic under these conditions. It should be noted also that, although the overliming injury was overcome by increasing the amount of phosphate in the soil solution, liming to high pH values did not decrease the concentration of water-soluble phosphate in the soil.

TABLE 2.—*The yield of corn and the solubility of phosphate in Dekalb loam (soil No. 609) receiving different proportions of calcium and magnesium carbonate.*

Pot Nos.*	Ratio of $CaCO_3$ to $MgCO_3$ (added at beginning of experiment)	pH value after liming	Average yield of corn (oven-dry weight), grams	Inorganic PO_4		Available PO_4 (Truog method), p.p.m.
				Water extract (1:5 soil basis), p.p.m.	Soil solution, p.p.m.	
1–2	——	4.55	23.5	0.37	0.13	94
3–4	1:0	6.45	17.4	0.53	0.19	77
5–6	½:½	6.45	27.5	0.68	0.23	85
25–26	1:0	6.60	25.2	1.22	0.41	164
27–28	1:0	7.55	19.0	1.52	0.39	212
19–20	¾:¼	7.55	22.7	1.69	0.43	206
21–22	½:½	7.90	26.4	2.03	0.71	212
23–24	¼:¾	7.80	30.1	2.98	1.16	205

*Pots numbered 19 to 28, inclusive, received additional phosphate as NaH_2PO_4 at a rate equivalent to 160 pounds P_2O_5 per acre before planting corn.

The data in the previous experiment do not show the extent of the liming injury so far as decreased yields are concerned, since the unlimed soil was too acid to give optimum growth and the lowest rate of liming caused injury. To show the extent of injury a supplementary experiment was conducted using soil from the same source. After liming the soil in duplicate pots with calcium carbonate to obtain pH values of approximately 5.5, 6.5, and 7.5, the pots were allowed to remain at approximately optimum moisture for 1 month. Superphosphate, muriate of potash, and urea were then added at the rates of 500, 135, and 150 pounds per acre, respectively, and the pots planted to corn. Good growth was obtained at pH 5.5, but the characteristic purplish leaf color and poor growth were obtained at pH 6.5 and 7.5. A photograph of the plants when they were 2 months old is shown in Fig. 4.

EXPERIMENT III. LIMING INJURY STUDIES WITH RAPE AND CORN, 1932–33

This experiment was started with the purpose of obtaining further information particularly in regard to the use of different liming materials and to the effect of overliming injury on plant composition. The soil was obtained from the same field as in the previous experiment. Four different liming materials were used, namely, pure calcium carbonate, calcium limestone, dolomitic limestone, and calcium silicate. These were added at two different rates, 16 2-gallon pots being limed to approximately pH 5.8 and an equal number being limed to approximately pH 7.0. The liming treatments as well as the additional differential treatments with superphosphate and silica gel are shown in the first two columns of Tables 3 and 4. The high-calcium limestone and the dolomitic limestone were both of approximately the same degree of fineness, 25% being composed of 60 to 100-mesh separates, and 75% of material finer than 100-mesh. The calcium silicate was a commercial by-product obtained from the Electric Smelting and Aluminum Company of Sewaren, N. J. According

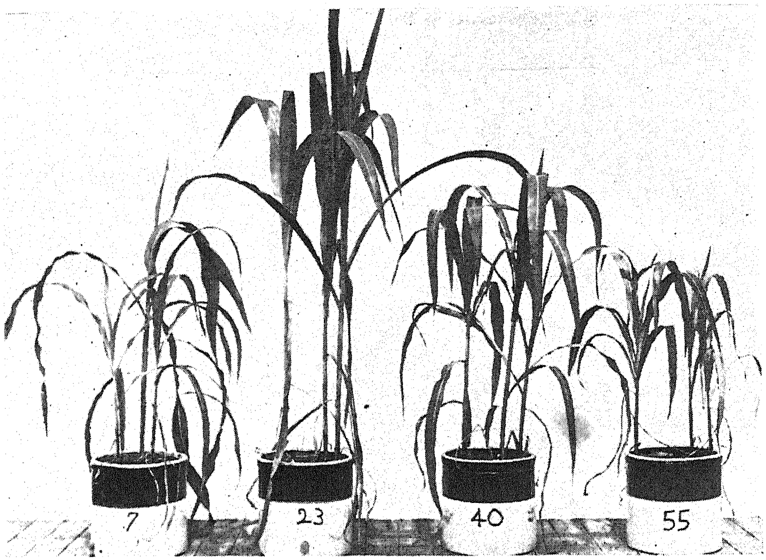

FIG. 4.—Growth of corn on Dekalb loam soil limed to different pH values, plants 2 months old. Pot No. 7, pH 4.55, 38.1 grams corn; No. 23, pH 5.50, 80.9 grams corn; No. 40, pH 6.60, 57.6 grams corn; No. 55, pH 7.55, 19.4 grams corn.

TABLE 3.—*Yield of rape on a Dekalb loam (soil No. 647) limed to two different pH values and receiving different treatments.*

Soil treatment*		Yield (dry weight), grams		PO_4 in 1:5 water extract (soil basis), p.p.m.		Ca in soil solution, p.p.m.	
Liming materials	Superphosphate, lb. per acre	A†	B	A	B	A	B
$CaCO_3$	None	—	5.3	0.15	0.16	494	882
$CaCO_3$	500	9.7§	7.0	0.18	0.18	308	912
$CaCO_3$	1,000	10.1	8.3	0.25	0.42	—	—
$CaCO_3$	2,500	11.5	10.0	0.60	0.64	623	906
$CaCO_3$‡	500	11.8	9.1	0.30	0.49	319	903
Dolomitic limestone	500	10.8	9.2	0.26	0.37	134	287
Calcium limestone	500	11.5	6.9	0.19	0.22	295	1175
Calcium silicate	500	11.5	10.1	0.31	0.58	226	566

*All pots received a uniform application of nitrogen and potash.
†A refers to medium liming, approximately pH 5.8; B to high liming, approximately pH 7.0.
‡Received silica gel at the rate of 4,000 pounds per acre.
§Some injury from naphthalene fumigation.

to the analysis reported by Scheidt (30), it contained 49.1% CaO, 3.2% MgO, and 6.0% Na_2O. After the liming materials had been allowed to react with the soil for 6 weeks, all pots received a uniform application of muriate of potash at the rate of 100 pounds per acre and urea at the rate of 150 pounds per acre. The superphosphate and silica gel shown in Tables 3 and 4 were also applied at this time. All pots were seeded to rape on October 26.

TABLE 4.—*Yield of corn on a Dekalb soil (soil No. 647) limed to two different pH values and receiving different treatments.*

Soil treatment*		Yield (dry weight), grams		pH values		PO_4 in 1:5 water extract (soil basis), p.p.m.	
Liming material	Superphosphate, lbs. per acre	A†	B	A	B	A	B
$CaCO_3$	None	9.7	2.7	5.75	7.00	0.24	0.23
$CaCO_3$	500	28.7	8.7	5.85	7.05	0.35	0.30
$CaCO_3$	2,500	43.5	34.5	5.70	6.95	1.58	1.60
$CaCO_3$‡	500	31.5	20.6	5.65	6.95	0.71	0.59
Dolomitic limestone	500	33.1	27.2	5.75	6.85	0.52	0.47
Calcium limestone	500	26.4	8.8	5.80	7.05	0.33	0.27
Calcium silicate	500	30.4	20.2	5.85	7.10	0.49	0.68

*All pots received a uniform application of nitrogen and potash.
†A refers to medium liming, approximately pH 5.8; B to high liming, approximately pH 7.0.
‡Received silica gel at the rate of 4,000 pounds per acre.

PLANT GROWTH

After approximately 3 weeks the plants in the cultures limed to pH 7.0 were making much poorer growth than those limed to pH 5.8, with the exception of those receiving the high rate of superphosphate, the dolomitic limestone, or the calcium silicate. These differences in growth became even more apparent during the next 4 or 5 weeks, except that the plants from the cultures of pH 7.0 receiving silica gel recovered from the overliming injury. Thereafter a long period of cloudy weather caused the plants to make very slow growth, and the differences in growth between the best and poorest plants decreased. The rape was harvested on January 17, and the oven-dry weights are reported in Table 3. No significant differences in yield were obtained from the different liming treatments on soil limed to a pH of approximately 5.8. Unfortunately, with the medium liming series naphthalene fumigation caused severe injury to the plants of the "no phosphorus" treatment and slight injury to the plants of the "calcium carbonate-regular phosphorus" treatment. When the soil was limed to pH values of approximately 7.0 significant differences in yield were obtained with the different liming materials, the yield with dolomitic limestone and calcium silicate being considerably greater than with calcium carbonate or high calcium limestone. Moreover, as in the previous experiment, large amounts of superphosphate or of silica gel materially increased the yield.

After harvesting the rape the soil in each pot was mixed, the plant roots removed, and samples of soil taken for laboratory studies.

The potted soils were then brought to 15% moisture, allowed to stand for 3 to 5 days, and the soil solution displaced (5) from approximately 1-kilogram samples. After displacement the soil samples were placed back in the pots and allowed to dry. The soil in each pot was then thoroughly mixed and refertilized as for the rape crop. Corn was planted on February 18. A top-dressing of nitrate of soda at the rate of 300 pounds per acre was applied on April 17, and the corn was harvested on May 12. The yield data are given in Table 4.

With "medium liming" there was little difference in the yields as a result of the different liming materials, but with "high liming" marked differences in growth were obtained, the yield with dolomitic limestone and calcium silicate being about three times as high as with calcium limestone and calcium carbonate. Likewise, when large amounts of silica gel or of superphosphate were applied in addition to calcium carbonate, the yield was increased approximately two to four times. As in the other experiments, the yield data were closely related to the extent of purpling of the leaves during growth.

SOIL STUDIES

The pH values and the content of inorganic phosphate in the soil extract of samples taken after the removal of each crop are given in Tables 3 and 4. As in the previous experiment, silica gel materially increased the concentration of water-soluble phosphates. Likewise, calcium silicate and dolomitic limestone additions resulted in much higher concentrations of water-soluble phosphorus than did additions of calcium carbonate and high-calcium limestone. These differences, it will be noted, were obtained both with the medium and high rate of liming. Another point of considerable interest is the fact that with the exception of the cultures receiving calcium silicate, there was no consistent difference in the water-soluble phosphate of cultures receiving different amounts of the same liming material. This is somewhat different from the results obtained in Experiment II where liming to pH 7.5 resulted in a higher soluble phosphate concentration than liming to pH 6.5. It is apparent from both experiments, however, that the injury from overliming is not associated with a lower amount of water-soluble PO_4 in the soil extract. This is further shown by data obtained from a study of soil samples taken immediately before the first fertilization in Experiment I and presented in Fig. 5. Although all of these soils showed considerable liming injury with alfalfa, in only one out of the three was there a significant decrease in water-soluble phosphate at high pH values.

As shown in Table 3, the calcium concentration is much higher in the displaced soil solution of soils limed to pH 7.0 than in those of soils limed to pH 5.8. Additions of silica gel or large amounts of superphosphate which materially decreased overliming injury did not reduce the calcium concentration of the soil solution. This indicates that high concentrations of calcium are not directly related to the poor growth obtained, or else that any injurious effects which might be due to high amounts of calcium are overcome by increasing the amounts of available phosphorus.

PLANT ANALYSIS

As will be seen in Table 5, the plants grown on the heavily limed soil are considerably higher in calcium on the dry plant basis than those grown on the soils limed to approximately pH 5.8. The percentages of phosphorus on the same basis vary but slightly. The calcium-phosphorus ratio, however, is much higher in the plants grown on the heavily limed soil. Moreover, with the high liming treatments, there appears to be a relationship between yields and calcium-phos-

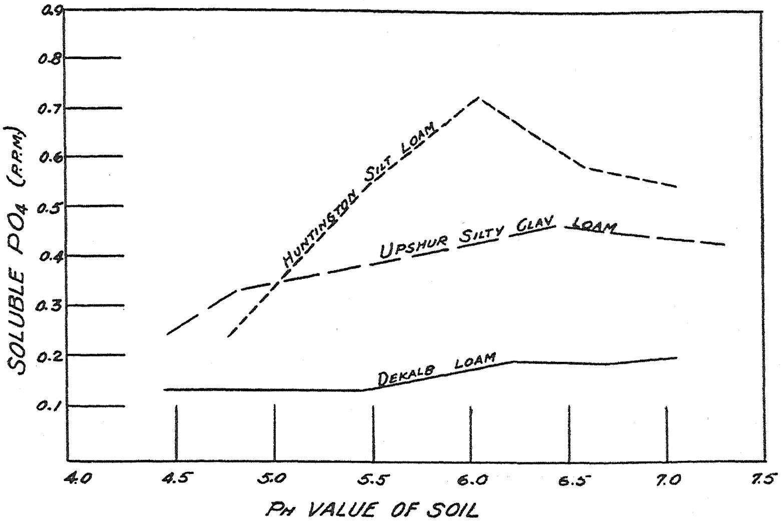

FIG. 5.—The relationship between the pH value and the water-soluble phosphate of soils recently limed to different pH values.

TABLE 5.—*The percentage of calcium, magnesium, and phosphorus in corn plants grown on a Dekalb soil receiving different amounts of liming materials and other treatments.*

Soil treatment		Ca %		Mg %		P %		Ca:P ratio	
Liming material	Super-phosphate, lbs. per acre	A*	B	A	B	A	B	A	B
$CaCO_3$.....	None	1.250	1.98	0.225	0.055	0.143	0.092	4.5	11.1
$CaCO_3$.....	500	0.806	1.64	0.159	0.104	0.121	0.119	3.4	7.1
$CaCO_3$.....	2,500	0.745	1.07	0.078	0.044	0.123	0.101	3.2	5.5
$CaCO_3$†	500	0.867	1.30	0.096	0.138	0.104	0.102	4.3	6.6
Dolomitic limestone.	500	0.378	0.53	0.580	1.018	0.103	0.099	1.9	2.7
Calcium limestone.	500	0.771	1.81	0.175	0.197	0.113	0.113	3.5	8.3
Calcium silicate...	500	0.590	1.20	0.355	0.520	0.123	0.098	2.5	6.3

*A refers to medium liming, approximately pH 5.8; B to high liming, approximately pH 7.0.
†Soil received silica gel at rate of 4,000 pounds per acre.

phorus ratio if the cultures receiving the magnesium-containing liming materials, *viz.*, dolomitic limestone and calcium silicate, are excluded.

In considering plant analysis data it should be emphasized that percentage composition based on the dry plant weight is oftentimes inadequate, since the ash content of plants depends to some extent on the size of the plants or their stage of development. Thus, stunted plants are often found to contain a higher content of ash than those making normal growth. It seemed desirable, therefore, to determine the percentage of ash in these plants and to express the content of calcium, magnesium, and phosphorus on the ash basis. These data are given in Table 6. It will be first noted that plants making poor growth due to a lack of phosphorus, or plants stunted as a result of liming injury have a much higher percentage of ash than those making normal growth. As a consequence, the percentage of calcium on the ash basis is not much different for plants receiving near optimum amounts of lime than for corresponding plants grown on the same soil receiving excessive amounts of liming materials. The percentage of phosphorus, however, is lower in the ash of plants grown on the soil receiving the large amounts of liming materials, a point that may be of some significance in view of the fact that overliming injury was found to be overcome by treatments which increased the water-soluble phosphorus in the soil.

TABLE 6.—*The percentage of calcium, magnesium, and phosphorus in the ash of corn plants grown on a Dekalb soil receiving medium and high liming treatments.*

Soil treatment		Ash %		Ca %		Mg %		P %	
Liming material	Superphosphate, lbs.per acre	A*	B	A	B	A	B	A	B
$CaCO_3$........	None	9.14	——†	13.7	—	2.47	—	1.57	—
$CaCO_3$........	500	4.36	9.00	18.5	18.3	3.63	1.16	2.78	1.32
$CaCO_3$........	2,500	3.69	4.28	20.5	25.0	2.12	1.03	3.34	2.36
$CaCO_3$‡........	500	5.21	7.58	16.6	17.2	1.84	1.82	2.00	1.35
Dolomitic limestone........	500	3.95	5.50	9.6	9.6	14.70	18.50	2.61	1.80
Calcium limestone........	500	4.09	10.81	18.9	16.7	4.28	1.82	2.76	1.04
Calcium silicate	500	4.58	7.00	12.9	17.1	7.77	7.45	1.69	1.40

*A refers to medium liming, approximately pH 5.8; B to high liming, approximately pH 7.0.
†Insufficient plant material left for determination of ash.
‡Received silica gel at rate of 4,000 pounds per acre.

With the exception of the plants receiving dolomitic limestone or calcium silicate treatments, the percentage magnesium on the ash basis is much lower where the plants received excessive amounts of liming materials. It is also interesting to note that a good growth of corn was obtained at high pH values when the calcium-magnesium ratio in the plant varied from about 23 to 1 to as low as 0.5 to 1.0.

GENERAL DISCUSSION

The beneficial effect of large amounts of phosphates in overcoming liming injury obtained in this study is in agreement with results obtained by Scarseth and Tidmore (29) in some recent studies on phosphate fixation. Studying the effect of different sources of phosphates when applied at rates varying from 48 to 144 pounds P_2O_5 per acre, they obtained less decreased yields of sorghum from liming to pH 6.5 where the larger rate of phosphorus fertilizers had been applied.

Zimmerly (37) likewise found that heavy phosphate fertilization reduced the injury from chlorosis with snap beans grown at pH values slightly below neutrality, although he concluded from his plant analysis data that the chlorosis was not attributable to phosphorus deficiency.

In the present study it has been established that the injury to plant growth obtained by overliming an acid Dekalb loam soil is largely overcome by the additions of large amounts of phosphate fertilizer or by other soil treatments which increase the water-soluble phosphate in the soil. Thus, the beneficial effect of silica gel and of calcium silicate can be explained by the fact that the water-soluble phosphorus in the soil was, in general, more than doubled, possibly due to the formation of calcium silico-phosphate compounds (19, 28), which, according to Körber and Trömel (15), have a high solubility in ammonium citrate solution. Likewise, the beneficial effect obtained by substituting magnesium carbonate for a part of the calcium carbonate or by the use of dolomitic limestone instead of high calcium limestone is no doubt due to the formation in the soil of magnesium phosphate compounds of relatively high solubility. In view of these results it can be concluded that plants grown on the excessively limed soils studied made poor growth due to a disturbed phosphate nutrition. It is not readily evident, however, why the plants suffered from a lack of available phosphorus on such overlimed soils, especially in view of the fact that the concentration of water-soluble phosphorus in the soil was in some cases increased and in others not affected by excessive liming. It would appear either that the concentration of water-soluble phosphorus in the soil extract is not a true measure of phosphate availability, or else that under the conditions brought about in the soil by overliming, plants require larger amounts of soluble phosphorus for normal growth than where smaller or optimum amounts of lime are used. McGeorge (18) concluded from electrodialysis studies that plants require more soluble phosphate on alkaline than on neutral or slightly acid soils for normal growth, whereas Loew (16), Truog (34), and others have suggested a relationship between the calcium-magnesium balance in the soil solution and phosphate assimilation by plants.

Neither is it clear why the injury to plant growth from excessive liming is only temporary. It was found, however, in a study not reported in this paper that a Dekalb silt loam soil limed to approximately pH 7.0 contained a much higher amount of water-soluble phosphorus after it had been allowed to remain in a pile in the field for a period of 3 years than immediately after liming, and a considerably higher amount than did the unlimed soil similarly treated. This is in agreement with the work of Greenhill (11). This investigator found less response to phosphorus fertilizers 1 year after than immediately after liming, and concluded that heavy additions of lime slowly render available to the plant some of the original reserves of phosphate in the soil.

The results obtained in this investigation, therefore, should not be considered contradictory to the generally recognized principle that the liming of acid soils tends to make the soil phosphates more soluble and available (7, 11, 24, 27, 31, 35). It should be clearly recognized that the immediate effects of liming, especially if in excessive amounts, may be entirely different, so far as the availability of phosphates to plants is concerned, than the ultimate effect; Whereas, plants grown on soils to which large amounts of liming materials have recently been added may show symptoms of phosphate starvation and respond markedly to high phosphate fertilization, this temporary condition is gradually overcome and the lime slowly increases the availability of the soil phosphorus. Karraker's (13) results, showing a delayed effect of liming, are of interest in this connection.

In view of the beneficial effects of additions of silica gel in overcoming overliming injury and in increasing the water-soluble phosphates in the soil, it is believed that one of the important corrective factors under natural conditions is the colloidal silica and silicates present in soils. Other factors, however, are probably involved in the recovery from overliming.

Since overliming injury of the type described in this paper occurs on soils limed to pH 6.5 or even less, it is evident that on sandy soils especially care should be taken in the amounts of lime used at any one time. Although the injury is only temporary and is not likely to be as important under field as under greenhouse conditions, overliming injury to a more or less degree is conceivable under many field conditions. When the lime is applied as a top dressing such as for pastures, it should be realized that the lime moves downward very slowly, and that the surface inch or two of soil, may, therefore, receive a large excess even though the application on the plowed-depth basis is not large. Moreover, in reporting the results of field and especially greenhouse investigations, the amounts and kind of liming material used and the acidity of the soil before and after the applications are made should be considered essential data for a proper interpretation of the results obtained. This would be especially true in case of phosphate availability studies.

SUMMARY

Greenhouse studies were conducted with the purpose of determining the cause of the injurious effects of overliming on plant growth. The results obtained may be briefly summarized as follows:

1. Nine out of 10 acid soils ranging in pH from 4.4 to 5.6 gave poorer growth of alfalfa when brought to pH values near neutrality than when lower amounts of calcium carbonate were used, the average decreased yields when the pH values were slightly above 7.0

being 46%. With five of the nine soils the overliming injury to alfalfa disappeared after the first year.

2. Corn grown on an acid Dekalb loam which had been limed to pH values of approximately 6.5 and 7.5 showed marked injury and developed a light green to purplish color characteristic of phosphorus starvation. Additions of manganese sulfate, magnesium sulfate, ferrous sulfate, iron humate, or large amounts of muriate of potash did not correct this condition. The additions of large amounts of mono-calcium phosphate, mono-potassium phosphate, or silica gel, however, overcame the injury. Likewise the substitution of increasing amounts of magnesium carbonate for calcium carbonate, up to 75%, markedly improved growth and produced normal leaf color where the largest amount was added.

3. The materials that overcame liming injury materially increased the water-soluble phosphate in the soil solution and soil extract.

4. In a comparison of four different liming materials added in sufficient amounts to bring an acid Dekalb loam to pH 7.0, corn and rape made much better growth with dolomitic limestone or calcium silicate than with calcium limestone or calcium carbonate; the plants in the latter cases likewise showed marked symptoms of phosphate deficiency. The differences thus obtained were found to be explained by the larger concentrations of water-soluble phosphate where the dolomitic limestone and calcium silicate sources had been used. When the liming materials were added in amounts to bring the soil to pH 5.8, no liming injury was obtained and there was little difference in growth from the use of the various liming materials.

5. The corn plants grown on the soil limed to pH 7.0 had a higher ash content and a lower percentage of magnesium and phosphorus on the ash basis than plants grown at pH 5.8. Excluding the dolomitic limestone treatment some evidence was obtained of a relationship between the injury from excessive liming and the calcium-phosphorus ratio of plants.

6. It is concluded that the temporary overliming injury obtained in these experiments is due to a disturbed phosphate nutrition.

LITERATURE CITED

1. AMES, J. W., and SCHOLLENBERGER, C. J. The availability of phosphorus in calcareous and non-calcareous soils. Ohio Agr. Exp. Sta. Bul. 380. 1924.
2. BAUER, F. C. Response of Illinois soils to limestone. Ill. Agr. Exp. Sta. Bul. 405 : 301–363. 1934.
3. BLEDSOE, R. P. Lime, potash and alfalfa on Piedmont soils. Jour. Amer. Soc. Agron., 21 : 792. 1929.
4. BUIE, T. S., CURRIN, R. E., KYZER, E. D., and WARNER, J. D. Fertilizer rotation experiments at the Pee Dee Station. S. C. Agr. Exp. Sta. Bul. 262 : 25. 1929.
5. BURD, JOHN S., and MARTIN, J. C. Water displacement of soils and the soil solution. Jour. Agr. Sci., 13 : 265–295. 1923.
6. FINCH, A. H., ALBERT, D. W., and KINNISON, A. F. A chlorotic condition of plants in Arizona related to iron deficiency. Proc. Amer. Soc. Hort. Sci., 30 : 431–434. 1933.
7. FUDGE, J. F. The influence of various nitrogenous fertilizers on the availability of phosphate and potassium. Ala. Agr. Exp. Sta. Bul. 227. 1928.
8. GILBERT, B. E., and MCLEAN, F. J. A "deficiency disease". The lack of available manganese in a lime induced chlorosis. Soil Science, 26 : 27–32 1928.

9. GILE, P. L., and CARRERO, J. O. Causes of lime induced chlorosis and availability of iron in the soil. Jour. Agr. Res., 20 : 33–61. 1920.

10. ———— and CARRERO, J. O. Efficiencies of phosphate fertilizers as affected by liming and by the length of time the phosphates remained in Porto Rican soils. Jour. Agr. Res., 25 : 171–194. 1923.

11. GREENHILL, A. W. The availability of phosphatic fertilizers as shown by an examination of the soil solution and of plant growth. Jour. Agr. Sci., 20 : 559–572. 1930.

12. HOCKENSMITH, R. D., GARDNER, R., and KEZER, A. The effect of depth of placement on the availability of superphosphate in calcareous soils. Soil Science, 36 : 35–40. 1933.

13. KARRAKER, P. E. The delayed effect of liming. Soil Science, 27 : 147–148. 1927.

14. KLING, M., and ENGELS, O. Relation between soil reaction and the content of root-soluble phosphoric acid and potash. Zeit. Pflanzenernähr., Düngung u. Bodenk., 12 : 32–38 (C. A. 27, 1700). 1933.

15. KÖRBER, FREDERICK, and TRÖMEL, GERHARD. Forschungen über den Aufbau der Phosphatschlacken und ihre Bedeutung für die Thomasmehlerzengung. Arch. Eisenhüttenwesen, 7 : 7–20. 1933.

16. LOEW, OSCAR. The effect of calcium upon the physiological function of magnesium. Ernähr. Pflanze, 27 : 97–101; 121–122. 1931.

17. MACINTIRE, W. H., SHAW, W. M., and YOUNG, J. B. The repressive effect of lime and magnesia upon soil and subsoil potash. Jour. Agr. Sci., 20 : 499–509.

18. MCGEORGE, W. T. Electrodialysis as a measure of phosphate availability in soils and the relation of soil reaction and ionization of phosphates to phosphate assimilation. Ariz. Agr. Exp. Tech. Bul. 38. 1932.

19. ———— and BREAZEALE, J. F. The relation of phosphate availability, soil permeability and carbon dioxide to the fertility of calcareous soils. Ariz. Agr. Exp. Tech. Bul. 36. 1931.

20. MANN, H. B. Availability of manganese and iron as affected by applications of calcium and magnesium carbonates to the soil. Soil Science, 30 : 117–141. 1930.

21. MIDGLEY, A. R. Overliming acid soils. Jour. Amer. Soc. Agron., 10 : 822–835. 1932.

22. ———— and WEISER, V. L. Need and use of lime on Vermont soils. Vt. Agr. Exp. Sta. Bul. 371. 1934.

23. PARKER, F. W., and FUDGE, J. F. Soil phosphorus studies: I The colorimetric determination of organic and inorganic phosphorus in soil extracts and in the soil solution. Soil Science, 24 : 109–118. 1927.

24. ———— and TIDMORE, J. W. The influence of lime and phosphatic fertilizers on the phosphorus content of the soil solution and soil extracts. Soil Science, 21 : 425–441. 1926.

25. PETTINGER, N. A., HENDERSON, R. G., and WINGARD, S. A. Some nitritional disorder in corn grown in soil cultures. Phytopath., 22 : 33–51. 1932.

26. PIERRE, W. H., and PARKER, F. W. The use of collodion sacks in obtaining clear soil extracts for the determination of water soluble constituents. Soil Science, 23 : 13–32. 1927.

27. SALTER, R. M., and BARNES, E. E. Relation of soil reaction to phosphate response in field experiments. Paper presented at the Soils Section of Amer. Soc. of Agronomy, Washington, D. C., November 16, 1934.

28. SCARSETH, G. D. The mechanism of phosphate retention by natural alumino-silicate colloids. Jour. Amer. Soc. Agron., 27 : 596–616. 1935.

29. ———— and TIDMORE, J. W. The fixation of phosphate by clay soils. Jour. Amer. Soc. Agron., 26 : 152–162. 1934.

30. SCHEIDT, ALFRED W. A comparison of calcium silicate, carbonate and hydrate as fertilizer materials with experimental data. Presented at the meeting of the Amer. Chem. Society at Boston, Mass., September 12, 1917.

31. SNIDER, H. J. A chemical study of a soil under long-continued field experiments. Jour. Amer. Soc. Agron., 26 : 946–953. 1934.

32. TRUOG, E. The utilization of phosphates by agricultural crops, including a new theory regarding the feeding power of plants. Wis. Agr. Exp. Sta. Res. Bul. 41. 1916.

33. ————. The determination of the readily available phosphorus of soils. Jour. Amer. Soc. Agron., 22 : 874–882. 1930.
34. ————. Available calcium and magnesium in relation to phosphate utilization. Jour. Amer. Soc. Agron., 23 : 1055. 1931.
35. ————. Phosphates largely unavailable to plants when soil is acid. Wis. Agr. Exp. Sta. Bul. 425, p. 59. 1933.
36. WILLIS, L. G. Response of oats and soybeans to manganese on some coastal plain soils. N. C. Agr. Exp. Sta. Bul. 257. 1928.
37. ZIMMERLEY, H. H. Truck Crop investigations. Effects of heavy applications of phosphorus on the inter-relation of soil reaction, growth and partial chemical composition of lettuce, beets, carrots and snap beans. Va. Truck Exp. Sta. Bul. 73 : 863–928. 1930.

THE EFFECT OF DILUTION ON THE SOLUBILITY OF SOIL PHOSPHORUS[1]

HUGH DUKES[2]

SINCE the water-soluble phosphorus in most humid soils is small studies dealing with specific influences of dilution on the behavior of soil phosphorus are limited; yet a number of papers have suggested a possible influence of dilution on the solubility of phosphorus. Hibbard (2)[3] reports that the amount of PO_4 dissolved increases as the volume of solvent is increased up to a high dilution when dilute hydrochloric acid is used as a solvent, but that the concentration remains almost constant where water is used as the solvent, even with a dilution of 100 or more parts of water to 1 of soil. Lohse and Ruhnke (3) report a higher concentration of phosphorus with a 1 to 20 dilution (using a 0.01 m $KHSO_4$ solvent) than a dilution of 1 to 4 or 1 to 50. On the other hand, leaching a garden soil with a solution of $KHSO_4$ having a pH of 2.0 gave the greatest concentration of phosphorus in the first leaching. Bryan (1) reported that the phosphorus concentration of the successive leachates of different soils increased for a time, but a maximum concentration was not reported.

Soluble aluminum, calcium, and iron, as well as other elements, are known to decrease the concentration of phosphorus in the soil solution. In most cases these agents are more abundant than phosphorus and thus render phosphates insoluble. But in sandy soils with less quantities of fixing agents the conditions are different.

That calcium in the soil decreases the solubility of phosphorus is confirmed by the work of McGeorge (4) and others. McGeorge (4) reports that crops respond to phosphate fertilizers on calcareous soils even though they contain a high content of phosphates. Moreover, leaching such soils usually decreases the response of phosphate fertilizers.

In successive leachates of a soil Parker and Tidmore (5) found an increase in phosphorus and a decrease in calcium. Teakle (6) found that additions of ammonium oxalate to the soil solution greatly increased the phosphorus concentration.

The object of this study was to determine the effect of dilution (with water) on the solubility of phosphorus in sandy soils.

EXPERIMENTAL METHODS

The study was conducted under laboratory conditions, using a number of soils varying in texture and known to have a wide range in water-soluble phosphorus. The study consisted primarily in diluting the soils with varying amounts of distilled water and determining the phosphorus in the filtered solutions. The di-

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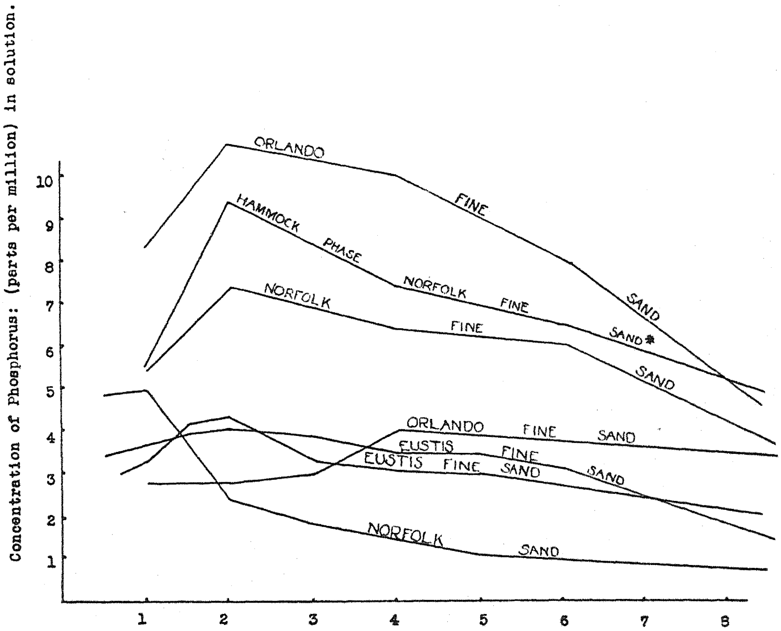
[3] Figures in parenthesis refer to "Literature Cited," p. 763.

lutions were made in erlenmeyer flasks, using 5-gram portions of soil and amounts of water varying from 2.5 cc to 75 cc. The contents of the flasks were shaken for 15 minutes and filtered. The phosphorus in the filtrates was determined colormetrically, using Truog's (7) method.



Dilution: Grams of water per gram of soil.

*** Parts per million phosphorus divided by 5.**

FIG. 1.—The effect of dilution on the solubility of soil phosphates.

RESULTS

The results shown in Fig. 1 indicate that the concentration of phosphorus in the soil solution increases on dilution for a time then gradually decreases with further dilution. This seemed to be true regardless of soil texture and content of phosphorus. In order to determine the influence of time of shaking the soil and water on the solubility of the phosphorus, two soils varying in phosphorus content were shaken for different periods of time (10 minutes, 30 minutes, 3 hours, and 15 hours). They were then filtered and the filtrates examined for phosphorus. The results are given in Table 1. Here it will be seen that the time of shaking influenced the total phosphorus in solution, but the proportions are not greatly altered. Lohse and Ruhnke (3) found this to be true, but, at a larger dilution than was used in this study. While Hibbard's (2) results do not agree with these results entirely, he obtained an increase in soluble phosphorus on dilution with a dilute acid.

TABLE 1.—*The influence of time of shaking on the solubility of soil phosphates.**

Soil used	Phosphorus in solution at intervals indicated, p.p.m. of P.			
	After 10 min.	After 30 min.	After 3 hrs.	After 15 hrs.
Orlando fine sand.	23.25	27.50	33.75	41.25
Bladen fine sand..	2.00	2.12	2.25	2.50

*Ratio of soil to water, 1 : 5.

Although it is commonly accepted that calcium has a positive effect on the solubility of soil phosphorus, no definite relation has been established. In order to ascertain the effect of calcium on the solubility of phosphorus in the soil solution, the soluble phosphorus and calcium were determined in the leachates of a number of soils. For this purpose, the soils were placed in tubes and leached in a manner similar to rainfall. The calcium was determined by the standard oxalate method and the phosphorus as previously indicated. The results are given in Table 2.

From Table 2 it may be seen that as the concentration of the calcium decreases, the concentration of the phosphorus increases but not in chemical equivalents. As a rule, the greatest concentration of phosphorus occurred at the first disappearance of calcium. Beyond this, the phosphorus decreased. It is interesting to note that this was true with high or low concentrations of calcium and phosphorus in the soil solutions.

These results seem to confirm those of Bryan (1) and Teakle (6) regarding the behavior of phosphorus on dilution. It would appear from these results that the phosphorus was not necessarily in combination with calcium. At least they do not occur in chemical equivalents. In all probability some of the soluble phosphorus was in combination with sodium, potassium, and ammonium as well as hydrogen in acid soil. The exact form would be difficult to determine. It is true that the method for determining calcium is not as delicate as that for phosphorus; however, the results should be in order. But the break in the concentration of phosphorus in the soil solution is quite evident regardless of soil used. This "break" or change in concentration seems to be due to the calcium present. It is of interest to note that the total amount of phosphorus in the soil solution is not directly related to the amount of calcium in the solution.

SUMMARY

Water extracts were made of a number of soil types, using with each type one part of soil to amounts of water varying from ½ to 15 parts. These extracts were analyzed for phosphorus. The results show that the concentration of phosphorus in the extracts increased with dilution up to a certain point for each soil, and upon further dilution decreased.

Samples of soil were also leached with distilled water, and the successive leachates analyzed for calcium and phosphorus. The results show that the phosphorus reached its maximum concentration at the point where the calcium first disappears from the leachates.

TABLE 2.—*The depressing effect of calcium on the soluble phosphorus in different soils.*

Successive leachings from 315 grams soil, cc	Concentration of phosphorus and calcium in successive leachings of different soils, p.p.m.							
	Bladen fine sand		Norfolk sand		Norfolk fine sand		Norfolk fine sand	
	P	CaO	P	CaO	P	CaO	P	CaO
25	6.0	2.48	8.0	4.48	11	8.00	4.0	2.45
25	7.5	1.28	9.0	2.12	15	4.50	4.4	2.12
50	8.2	0.00	9.5	0.24	18	1.32	4.2	0.34
50	7.8	0.00	9.7	0.24	21	0.68	4.0	0.28
50	8.0	0.20	9.0	0.00	23	0.04	4.5	0.30
50	7.8	0.00	8.0	0.00	24	0.00	4.9	0.34
50	7.0	0.00	7.0	0.00	20	0.00	5.4	0.14
50	6.5	0.00	—	—	18	0.00	4.7	0.00
50	—	—	—	—	17	0.00	4.6	0.00
50	—	—	—	—	—	—	4.5	0.00
50	—	—	—	—	—	—	4.6	0.00
50	—	—	—	—	—	—	4.4	0.00
50	—	—	—	—	—	—	—	—

Successive leachings from 315 grams soil, cc	Norfolk fine sand		Orlando fine sand		Bladen fine sand	
	P	CaO	P	CaO	P	CaO
25	1.0	11.3	15.0	10.72	0.45	6.8
25	1.5	13.0	18.0	4.52	0.48	3.7
50	2.1	0.9	27.0	1.00	0.49	2.5
50	2.6	0.27	30.0	0.08	0.51	1.5
50	2.9	0.10	28.0	0.00	0.57	0.73
50	3.2	0.09	25.0	0.00	0.62	0.51
50	3.0	0.00	22.0	0.00	0.65	0.49
50	2.7	0.00	—	—	0.65	0.33
50	2.6	0.00	—	—	0.65	0.15
50	2.5	0.00	—	—	0.62	0.00
50	—	—	—	—	0.55	0.00
50	—	—	—	—	0.57	0.00
50	—	—	—	—	0.52	0.00

LITERATURE CITED

1. BRYAN, O. C. The accumulation and availability of phosphorus in old citrus grove soils. Soil Science, 36 : 245–259. 1933.
2. HIBBARD, P. L. Chemical methods for estimating the availability of soil phosphates. Soil Science, 31 : 437–466. 1931.
3. LOHSE, H. W., and RUHNKE, G. N. Studies on readily soluble phosphate from soils: I. Extraction of readily soluble phosphates from soil by means of dilute acid potassium sulphate ($KHSO_4$). Soil Science, 35 : 437–457. 1933.
4. McGEORGE, W. T. Phosphate availability in alkaline calcareous soils. Journ. Amer. Soc. Agron., 25 : 351–354. 1933.
5. PARKER, F. W., and TIDMORE, J. W. The influence of lime and phosphatic fertilizers on the phosphorus content of the soil solution, and of soil extracts. Soil Science, 21 : 425–441. 1926.
6. TEAKLE, L. J. H. The phosphate in the soil solution as affected by reaction and cation concentration. Soil Science, 25 : 143–162. 1928.
7. TRUOG, EMIL. The determination of readily available phosphorus of soils Journ. Amer. Soc. Agron., 22 : 874–882. 1930.

NON-ACID-FORMING MIXED FERTILIZERS: II. THE VALUE OF DOLOMITIC LIMESTONE SUPPLEMENTS OF DIFFERENT DEGREES OF FINENESS AS MEASURED BY THE INCREASE IN WATER-SOLUBLE MAGNESIUM IN THE SOIL[1]

J. R. TAYLOR, JR., AND W. H. PIERRE[2]

THE recent development in the manufacture of mixed fertilizers of adding dolomitic limestone in order to make them non-acid forming or to supply available magnesium has raised the question as to the proper fineness of the limestone. From the manufacturer's standpoint there are certain objections to the use of very finely ground material. On the other hand, it is well recognized that the finer a limestone is ground, the quicker it reacts with the soil. In answering the question of proper fineness, therefore, consideration must be given, first, to the need or desirability of having the limestone used in mixed fertilizers react rapidly with the soil, and second, to the rate of reaction of dolomitic limestone of different degrees of fineness.

While the main advantage of non-acid-forming fertilizers over those that are acid-forming is, in general, the prevention of a harmful increase in soil acidity over a period of years; nevertheless, on sandy soils of relatively low pH value, the beneficial effect may be exerted in part during the first year. This is indicated by the results of Tidmore and Williamson (14)[3] and by the results obtained in an accompanying study by the writers (13). Moreover, it has been shown by Chucka (1), by Knoblauch and Odland (4), and by others that certain soils of the eastern United States are deficient in available magnesium. In order to overcome the deficiency of such soils, fertilizer manufacturers have been adding soluble magnesium salts to fertilizers at a relatively high cost per unit of magnesium oxide. If the magnesium deficiency could be corrected equally well by the substitution of dolomitic limestone, it is obvious that greater economy would result. The making of such a substitution will depend on how much of the magnesium of the dolomitic limestone becomes soluble during the first growing season. It is important, therefore, to compare magnesium sulfate and dolomitic limestone of different degrees of fineness with respect to their effect on the soluble magnesium content of the soil during the first few weeks after the fertilizer is applied.

The question of the relation between degrees of fineness and the rate of decomposition of dolomitic limestone has been studied by MacIntire, *et al.* (6, 7), Morgan and Salter (8), White (18), and others. These investigators have well established the general relation between degrees of fineness and rate of reaction, and also the fact that

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[3] Figures in parenthesis refer to "Literature Cited," p. 773.

dolomitic limestone reacts more slowly in the soil than does calcium limestone, especially with the coarser separates. No studies have been reported, however, where the dolomitic limestone was added as a part of the fertilizer mixture, nor where the amounts of water-soluble magnesium were determined after relatively short intervals of time.

The objectives of this investigation were as follows:

1. To compare the concentrations of soluble magnesium in the soil-fertilizer zone when magnesium sulfate and when dolomitic limestone of different degrees of fineness are used as the sources of magnesium in the fertilizer.
2. To determine the effect of the fineness of dolomitic limestone on its rate of decomposition in the soil-fertilizer zone when used as a constituent of mixed fertilizers.
3. To compare the rate of decomposition of dolomitic limestone obtained from different sources.

METHOD OF STUDY

This investigation was carried out in the greenhouse with a Dekalb silt loam of pH 5.4. All fertilizers used in the study had the composition of 4-10-6. In all cases three-fourths of the nitrogen was derived from ammonium sulfate and one-fourth from ammonium phosphate, the phosphorus partly from ammonium phosphate and partly from superphosphate, and the potash all from muriate of potash. As shown in Table 1, the fertilizers differed only in regard to the amount and kind of dolomitic limestone or of magnesium sulfate used as filler. All dolomitic limestone separates were obtained by wet screening.

After thoroughly mixing the bulk sample of soil and placing 4,000-gram samples in 22 1-gallon pots, the fertilizers were added and thoroughly mixed with the soil. In order to simulate as much as possible the soil-fertilizer zone under row applications in the field (13), the fertilizers were applied at a rate of 12,000 pounds per 2,000,000 pounds of soil. If it is assumed that in hill or row application the fertilizer is mixed with only one-tenth of the surface 6⅔ inches of soil, then the rate given above is comparable to 1,200 pounds per acre. After fertilization the soil was brought to approximately optimum moisture content and distilled water added at regular intervals to compensate for losses by evaporation. All treatments were in duplicate. After various intervals, soil samples were removed for determinations of soluble magnesium, nitrate nitrogen, and pH.

The water extract of the soils was obtained by the dialysis method (12) after the soil had been in contact with the water for 18 hours in the presence of sufficient toluene (1 cc per 125 cc water) to prevent denitrification. The pH was determined by the colorimetric method (12), nitrates by the phenoldisulfonic method, and magnesium by the method described by Kramer and Tisdall (5).

CONCENTRATION OF WATER-SOLUBLE MAGNESIUM IN THE SOIL-FERTILIZER ZONE

In Fig. 1 are shown the increases in water-soluble magnesium in the soil-fertilizer zone obtained when magnesium sulfate and when dolomitic limestone of different degrees of fineness were used as sources of magnesium in the fertilizer applied. Where no magnesium was applied in the fertilizer, the water-soluble magnesium found in

TABLE 1.—*Description of supplements used in fertilizers.*

Fertilizer No.	Magnesium compounds used in fertilizers*			Partial composition of dolomitic limestone	
	Source†	Fineness	Pounds per ton of fertilizer	$CaCO_3$ %	$MgCO_3$ %
1	—	—	—	—	—
2	Dolomitic limestone (B)	20–40 mesh	343	58.3	41.1
3	Dolomitic limestone (B)	60–80 mesh	343		
4	Dolomitic limestone (B)	Finer than 100 mesh	343		
5	Dolomitic limestone (B)	Finer than 100 mesh	228		
6	Dolomitic limestone (B)	Finer than 100 mesh	114		
7	Dolomitic limestone (B)	Mixture of different separates‡	343		
8	Dolomitic limestone (A)	Mixture of different separates‡	345	58.5	42.3
9	Dolomitic limestone (C)	Mixture of different separates‡	383	56.7	36.3
10	Dolomitic limestone (D)	Mixture of different separates‡	348	57.1	41.5
11	$MgSO_4.7H_2O$	—	131	—	—

*In addition to these materials, quartz sand was used in all cases in sufficient amounts to make the analysis 4–10–6.

†The four samples of ground dolomitic limestone were obtained from West Virginia, Ohio, Tennessee, and Alabama.

‡Mechanical analysis: All through 40-mesh sieve; 20% through 40-mesh but held on 60-mesh sieve; 20% through 60-mesh but held on 80-mesh sieve; 10% through 80-mesh but held on 100-mesh sieve; and 50% through 100-mesh sieve.

the soil varied from 28.1 p.p.m. after the 24-day period to 48.4 p.p.m. after 171 days. The increases are shown after 24, 52, 84, and 171 days. The dolomitic limestone "mixture" curve as shown in Fig. 1 represents the average increase obtained from the dolomite mixtures from the four different sources.

As was to be expected, the finer material reacted more quickly than the coarser particles and as the time increased more magnesium was brought into solution. The rate of solution of the finer than 100-mesh dolomitic limestone, the 60 to 80 mesh, and the dolomitic limestone "mixture" was rather rapid up to 84 days, but showed a considerable decrease thereafter. The 20 to 40 mesh curve showed a much slower rate of solution.

It is interesting to observe the similarity of the curves representing pure magnesium sulfate and finer than 100-mesh dolomitic limestone applied at one-third standard rate. The magnesium sulfate was used at a rate sufficient to supply 12.9 pounds of magnesium per ton of fertilizer and the one-third standard rate dolomitic limestone supplied 13.6 pounds. A comparison of these two curves shows that the dolomitic limestone finer than 100-mesh liberated just about as much soluble magnesium per pound of total magnesium added as did pure magnesium sulfate. In comparing the dolomitic limestone "mixture" and magnesium sulfate curves, it is seen that the former supplied slightly more soluble magnesium in the soil-fertilizer zone after 24 days and over twice as much after 84 days. Since about three times as much total magnesium was added in the dolomitic limestone "mixture", however, it is seen that for each unit of magnesium supplied it required, after the 24- and 84-day periods, respectively, 3 and 1½ times as much of the dolomitic limestone "mixture" as of magnesium sulfate to supply the same amount of soluble magnesium.

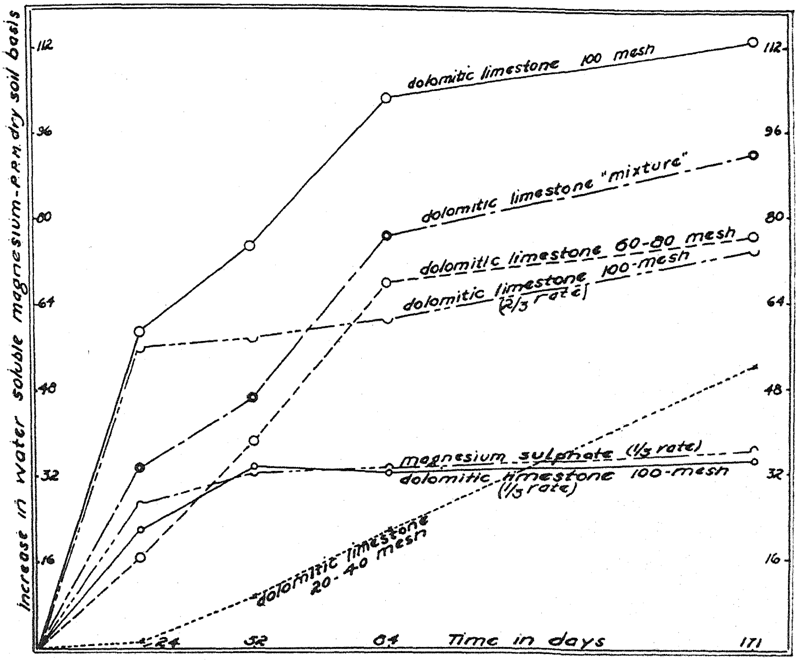

FIG. 1.—The relationship between fineness of dolomitic limestone and concentrations of water-soluble magnesium in the fertilized soil after various intervals of time.

It should be emphasized, however, that all the nitrogen used in the experiment was from acid-forming sources. With fertilizers containing relatively low percentages of acid-forming sources of nitrogen it is possible that the rate of solubility of dolomitic limestone would be somewhat less than that found in this experiment. Likewise, the rate of decomposition of limestone of different degrees of fineness would be influenced to some extent by the original acidity of the soil (11).

Table 2 shows the percentage recovery of water-soluble magnesium in the soil-fertilizer zone from the magnesium sulfate and dolomitic limestone treatments after various intervals of time. After 24 days, 69.2% of the magnesium from the magnesium sulfate treatment was recovered in the soil extract, and 85.9, 84.9, and 99.4% recovered after 52, 84, and 171 days, respectively. These figures show, as would be expected, that even though magnesium sulfate is considered as being 100% available to plants, only part of the magnesium added was recovered in the soil extract during the early periods. The remainder was probably present in exchangeable form, and likewise available to plants.

TABLE 2.—*The effect of source of magnesium and of fineness of dolomitic limestone on the soluble magnesium content of the soil after different periods of time.*

Source of magnesium in fertilizer	Pounds magnesium added per ton of fertilizer	Percentage magnesium recovered in soil extract after			
		24 days	52 days	84 days	171 days
Dolomitic limestone, 20–40 mesh	40.7	1.4	8.4	18.1	43.1
Dolomitic limestone, 60–80 mesh	40.7	13.9	31.9	56.2	63.5
Dolomitic limestone, 100 mesh	40.7	48.5	61.5	84.4	94.1
Dolomitic limestone (⅓ standard rate) 100 mesh	13.6	55.6	83.9	80.7	90.3
Dolomitic limestone (⅔ standard rate) 100 mesh	27.2	69.5	76.6	76.4	92.8
Dolomitic limestone, "mixture"*	41.1	27.6	38.1	62.9	75.1
$MgSO_4.7H_2O$	12.9	69.2	85.9	84.9	99.4

*Data represent an average obtained from the four dolomitic limestones of different sources. See Table 1 for chemical and mechanical analyses.

Assuming that the increase of soluble magnesium in the soil-fertilizer zone is a measure of decomposition, the comparison between the amounts of magnesium recovered from magnesium sulfate and from the various grades of dolomitic limestone can be used as a basis for determining the decomposition of the latter after various intervals of time. Using the percentage recovery of magnesium from readily soluble magnesium sulfate, given in Table 2, as a standard of 100, the decomposition of the different grades of dolomitic limestone at each date were calculated and are shown in Table 3. It is noted that the finer than 100-mesh dolomitic limestone is only 70% as effective as magnesium sulfate in increasing the soluble magnesium in the soil-fertilizer zone at 24 and 52 days when used at the standard rate, whereas when used at one-third standard rate it was practically as effective, as shown in Fig. 1. This is no doubt due to the fact that the more dolomite added, the longer it takes for all of it to react. The table emphasizes the fact that the coarse material reacted very slowly. After 24 days only 2% of the 20 to 40 mesh and 20% of the

60 to 80 mesh material had reacted, as compared with 70% of the finer than 100-mesh material. At the end of 84 days practically all the finer than 100-mesh dolomitic limestone had reacted as compared with 66% of the 60 to 80 mesh and only 21% of the 20 to 40 mesh. The decomposition at this time is of special interest because it probably represents the maximum that would be available during the first growing season. The dolomitic limestone "mixture" again represents the average results obtained from the dolomitic limestone from the four different sources. The calculated value of the "mixture" was figured from the results obtained from the individual separates as given in Table 3, and as can be seen these results agree well with the results of the dolomitic limestone "mixture" as obtained in the experiment.

TABLE 3.—*The effect of fineness of division of dolomitic limestone on its rate of decomposition in the soil as measured by the accumulation of water-soluble magnesium*

Fineness of dolomitic limestone used in fertilizer	Percentage decomposed based on increase in water-soluble magnesium in the soil after*			
	24 days	52 days	84 days	171 days
Finer than 20 mesh, coarser than 40 mesh	2.0	9.7	21.3	43.3
Finer than 60 mesh, coarser than 80 mesh	20.0	37.1	66.1	63.9
Finer than 100 mesh	70.1	71.5	99.4	94.7
Mixture of separates†	39.8	44.3	74.1	75.6
Mixture of separates, calculated value‡	45.8	53.3	79.9	78.8

*Amount of water-soluble magnesium obtained with magnesium sulfate used as standard of comparison.

†Data represent an average obtained from the four dolomitic limestones of different sources. See Table 1 for chemical and mechanical analyses.

‡Calculated from the result of the individual separates. Values for the 40–60 and 80–100 mesh separates assumed to be intermediate between the 20–40 and the 60–80 mesh separates in the former case and between the 60–80 and 100 mesh separates in the latter.

Morgan and Salter (8), working with three true dolomitic limestones on a Trumbull silt soil of pH 5.6, found that about 19% of the 50-mesh and 52% of the 100-mesh material had decomposed after 35 days. By interpolation in Fig. 1 for 35 days and assuming 50-mesh dolomitic limestone to be intermediate between the 20 to 40 and 60 to 80 mesh and the 100-mesh between the 60 to 80 and finer than 100-mesh, it is found that 12.5% of the 50-mesh and 37.5% of the 100-mesh material had decomposed. These results agree rather well when it is considered that two entirely different methods of determining decomposition were used. Morgan and Salter measured decomposition by determinations of residual carbonates, whereas in this investigation only soluble magnesium was considered.

ACCUMULATION OF NITRATE NITROGEN IN THE SOIL-FERTILIZER ZONE

It is well known that the addition of limestone to an acid soil increases nitrification, and it has been found in an accompanying investigation (13) that the use of non-acid-forming fertilizers materially affects nitrate accumulation in the soil-fertilizer zone. It seemed desirable, therefore, to study the effect of fineness of division of dolomitic limestone used as a constituent of mixed fertilizers on nitrification of the added ammonia in the soil-fertilizer mixture. Fig. 2 shows the accumulation of nitrate nitrogen in p.p.m. after 24, 52, 84, and 171 days. It is seen that the addition of dolomitic limestone has materially increased nitrification. This is especially noticeable where the separates were of 60 to 80 mesh or finer. After 24 days the finer than 100-mesh dolomite applied at standard rate in the fertilizer had practically doubled the accumulation of nitrate nitrogen over the check. This increase is maintained throughout the experiment and at the end of 171 days there is still twice as much nitrate nitrogen where finer than 100-mesh dolomitic limestone had been used as where no dolomite had been added. When the finer than 100-mesh separates at one-third, two-thirds, and standard rates are compared, it can be seen that the more dolomitic limestone is added, the greater is the accumulation of nitrate nitrogen. This increase is not so noticeable at 24 days, but as the time increases the differences between the different rates increase. It is interesting to note that the 20 to 40 mesh dolomitic limestone caused no increase in nitrate nitrogen accumulation over the check at either 24 or 52 days, but thereafter nitrification increased until after 171 days the 20 to 40 mesh was as effective as the 60 to 80 mesh material which had over 1½ times the accumulation of nitrate nitrogen as the check.

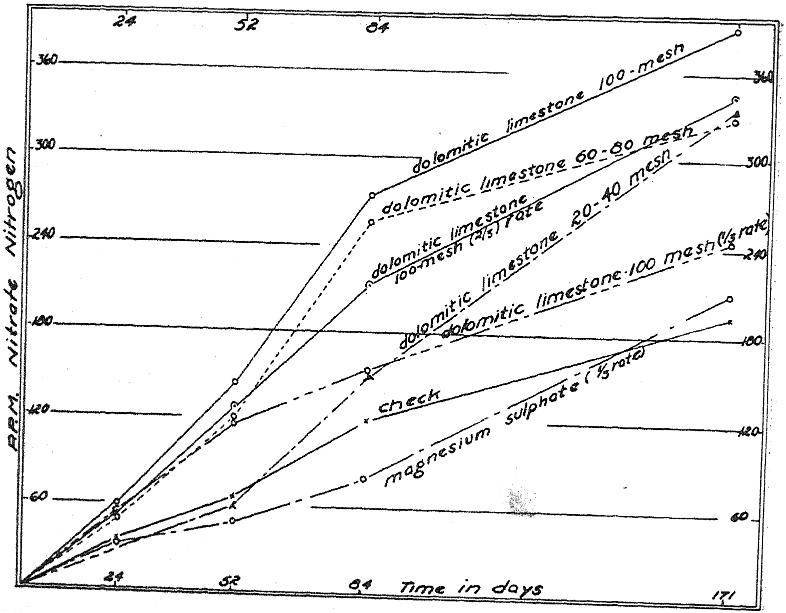

FIG. 2.—Relation between fineness of dolomitic limestone and concentration of nitrate nitrogen in the fertilized soil after various intervals of time.

The increased nitrate accumulation in the soil-fertilizer zone, as a result of the presence of dolomitic limestone in the fertilizer, may under certain conditions be of considerable importance since it has been shown by Tiedjens (16, 17) and others (2, 3, 9) that at low pH values nitrate nitrogen is more readily utilized by plants than is ammonia nitrogen.

COMPARISON OF DOLOMITIC LIMESTONE FROM FOUR WIDELY DIFFERENT SOURCES

In Table 4 is shown a comparison of dolomitic limestones from Alabama, Tennessee, Ohio, and West Virginia in regard to their effect upon the concentration of water-soluble magnesium, nitrate nitrogen, and hydrogen ions of the soil in the fertilized zone. The composition of these dolomitic limestones from various sources varied somewhat in percentage calcium and magnesium, as shown in Table 1, but the total amount of magnesium added to the soil was practically the same in all cases. The mechanical analysis, also given in Table 1, shows that the limestones were all of the same degree of fineness. If, as shown in Table 4, the results with dolomitic limestone A are taken as a standard of 100, it is seen that on the average dolomitic limestone B is 98% as effective in supplying water-soluble magnesium in the soil-fertilizer zone, whereas dolomitic limestones C and D are 108 and 118% as effective, respectively. The relative ranks change from 24 to 52 and from 52 to 84 and also from 84 to 171 days, so it might be said that there is no consistent difference between the different dolomitic limestones. Likewise, the differences in the accumulation of nitrate nitrogen in the soil-fertilizer zone from the use of dolomitic limestones from different sources are not great enough to be considered significant and are no doubt due to experi-

TABLE 4.—*Comparative effects of dolomitic limestone from different sources on the soluble magnesium, nitrate nitrogen, and hydrogen-ion concentration of soil in the fertilized zone.*

Source of dolomitic limestone*	Criteria of availability	Relative effects after†				
		24 days	52 days	85 days	171 days	Average
A	Water-soluble magnesium	100	100	100	100	100
B		96	102	105	91	98
C		94	129	89	120	108
D		114	124	105	129	118
A	Nitrate nitrogen	100	100	100	100	100
B		103	83	94	87	92
C		87	108	90	114	100
D		109	107	105	110	108
A	pH	5.50	5.30	5.08	4.83	—
B		5.49	5.33	5.28	4.83	—
C		5.55	5.33	5.15	4.85	—
D		5.48	5.15	5.10	4.80	—

*The four samples of ground dolomitic limestone were obtained from West Virginia, Ohio, Tennessee, and Alabama. See footnote 3 of Table 1 for mechanical analysis.

†With magnesium and nitrate nitrogen the values obtained with dolomitic limestone A are taken as a standard of 100.

mental error. The relative ranks change from one period to another and the average values over a 171-day period are remarkably close.

The pH values as given in Table 4 seem to vary rather closely with the corresponding accumulation of nitrate nitrogen in the heavily fertilized soil. This is to be expected when one considers the fact that the formation of nitrate nitrogen is an acidifying process. It is interesting to note that at the end of 171 days the dolomitic limestone from the four different sources are equally effective in maintaining the same hydrogen-ion concentration in the soil-fertilizer zone. The pH values are lower after 171 days than at the beginning of the experiment, however, even though the fertilizer was only slightly acid-forming. This is probably due to several factors, namely, increased salt concentration, partial decomposition of added dolomitic limestone, and possibly other factors (13).

SUMMARY

Studies were made in the greenhouse with a Dekalb silt loam soil of pH 5.4 to compare the concentration of soluble magnesium in the soil-fertilizer zone when magnesium sulfate and when dolomitic limestone of different degrees of fineness were used in the fertilizer as sources of magnesium. As measured by the concentration of soluble magnesium in the soil-fertilizer zone, the decomposition of dolomitic limestone of different degrees of fineness when used as a constituent of a mixed fertilizer was determined after 24, 52, 84, and 171 days. The rate of decomposition of four dolomitic limestones obtained from widely different sources was also studied.

The results show that after a period of 24 days the finer than 100-mesh dolomitic limestone, when used as a constituent of a mixed fertilizer, liberated in the soil-fertilizer zone practically as much magnesium as did pure magnesium sulfate containing an equivalent amount of magnesium. After the same period it required over 3 times as much 60 to 80 mesh and 35 times as much 20 to 40 mesh as 100-mesh dolomitic limestone to liberate the same amount of magnesium. However, the values obtained after 84 days, which might be taken as representing the maximum amount of magnesium that would be supplied to the growing crop the first year showed that it required only about 1½ and 5 times as much 60 to 80 and 20 to 40 mesh material, respectively, as of 100-mesh material. After 24 days it required about 3 times as much magnesium in the form of a dolomitic limestone "mixture" to supply as much magnesium in the soil-fertilizer zone as pure magnesium sulfate, but after 84 days only 1½ times as much was required.

As measured by the concentration of soluble magnesium, the finer the division of dolomitic limestone used in the production of non-acid-forming fertilizers, the greater the rate of decomposition in the soil-fertilizer zone. It seems evident from the data obtained in the experiment that if much benefit is to be expected from the use of dolomitic limestone in mixed fertilizers during the year in which it is applied, the material should all pass the 20-mesh sieve and a large part should pass the 60-mesh sieve.

Samples of dolomitic limestones from West Virginia, Ohio, Ten-

nessee, and Alabama were studied and it was found that the rate of decomposition of these dolomitic limestones as indicated by the concentration of magnesium, nitrate nitrogen, and hydrogen-ions in the soil-fertilizer zone was practically the same.

Since it has been shown by Tidmore and Simmons (15) and one of the writers (10) that many mixed fertilizers containing 3 to 4% nitrogen have an equivalent acidity of 200 to 400 pounds $CaCO_3$ per ton, it seems probable that if such fertilizers are made non-acid-forming by the use of finely ground dolomitic limestone, they should supply a large part, if not all, of the magnesium needs of plants, even when grown on magnesium-deficient soils.

LITERATURE CITED

1. CHUCKA, JAS. A. Magnesium deficiency in Aroostook potato soils. Amer. Pot. Jour., 11 : 29–35. 1934.
2. CLARK, H. E., and SHIVE, J. W. The influence of the pH of a culture solution on the rates of absorption of ammonia and nitrate nitrogen by the tomato plant. Soil Science, 37 : 203–225; 459–476. 1934.
3. DAVIDSON, O. W., and SHIVE, J. W. The influence of the hydrogen-ion concentration of the culture solution upon the absorption and assimilation of nitrate and ammonia nitrogen by peach trees grown in sand cultures. Soil Science, 37 : 357–385. 1934.
4. KNOBLAUCH, H. C., and ODLAND, T. E. A magnesium deficiency induced by previous fertilizer treatments. Jour. Amer. Soc. Agron., 26 : 609–615. 1934.
5. KRAMER, B., and TISDALL, F. F. A simple technique for the determination of calcium and magnesium in small amounts of serum. Jour. Biol. Chem., 47 : 475. 1921.
6. MACINTIRE, W. H. Influence of form, soil-zone and fineness of lime and magnesium incorporations upon outgo of calcium and magnesium. Soil Science, 22 : 21–30. 1926.
7. ————, SANDERS, K. B., and SHAW, W. M. The availability of hydrated lime, limestone, and dolomite of two degrees of fineness with supplements of red clover hay as measured by lysimeter leachings. Jour. Amer. Soc. Agron., 25 : 285–297. 1933.
8. MORGAN, M. FRANCIS, and SALTER, ROBERT M. Solubilities of limestones as related to their physical properties. Soil Science, 15 : 293–305. 1923.
9. NAFTEL, JAMES A. The absorption of ammonium and nitrate nitrogen by various plants at different stages of growth. Jour. Amer. Soc. Agron., 23 : 142–158. 1931.
10. PIERRE, W. H. A review of studies concerning residual acidity of mixed fertilizers. 1934 Year Book of Commercial Fertilizer. 1934.
11. ———— Neutralizing values and rates of reaction with acid soils of different grades and kinds of liming material. Soil Science, 29 : 137–158. 1930.
12. ———— and PARKER, F. W. The use of collodion sacks in obtaining clear soil extracts for the determination of water-soluble constituents. Soil Science, 23 : 13–32. 1927.
13. TAYLOR, J. R. JR., and PIERRE, W. H. Non-acid-forming mixed fertilizers: I. Their effect on certain chemical and biological changes in the soil-fertilizer zone and on plant growth. Jour. Amer. Soc. Agron., 27 : 623–641. 1935.
14. TIDMORE, J. W., and WILLIAMSON, J. T. Experiments with nitrogenous fertilizers and limestone. Amer. Fert., 79 : No. 11, 6. 1933.
15. ———— and SIMMONS, C. F. The use of limestone in mixed fertilizers. Ala. Agr. Exp. Sta. Circ. 67. 1934.
16. TIEDJENS, V. A. Factors affecting assimilation of ammonium and nitrate nitrogen, particularly in tomato and apple. Plant Physiol., 9 : 31–57. 1934.
17. ———— and ROBBINS, W. R. The use of ammonia and nitrate nitrogen by certain crop plants. N. J. Agr. Exp. Sta. Bul. 526. 1931.
18. WHITE, J. W. The value of limestone of different degrees of fineness. Pa. Agr. Exp. Sta. Bul. 149. 1917.

NOTE

A FIELD ASPIRATOR FOR EMASCULATING SWEET CLOVER FLOWERS[1]

THE method described by Kirk[2] for emasculating sweet clover flowers, using the suction developed by water pressure, has been successfully used in a greenhouse at the Fort Hays (Kansas) Branch Experiment Station. This method, however, is unsuited for use in the field where water is not available. To overcome this difficulty and to continue the breeding work in the field, a simple and efficient aspirator was developed in the spring of 1933 which provides the suction without the use of water.

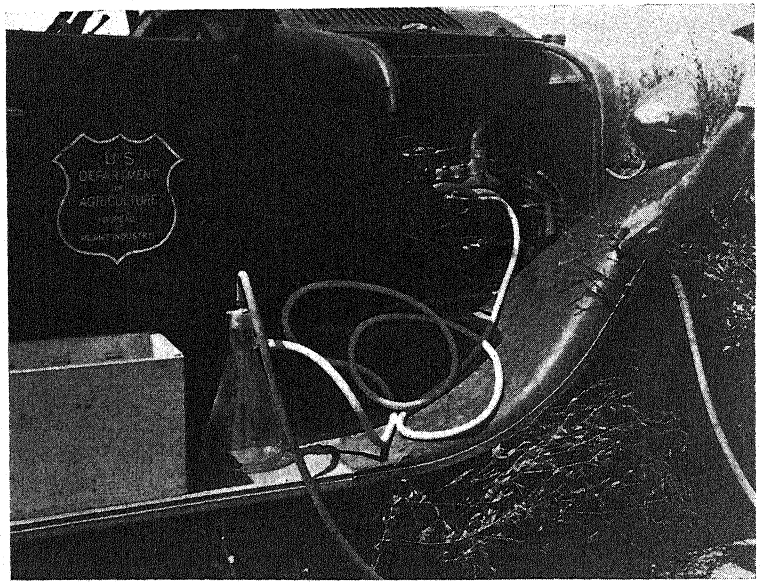

FIG. 1.—The manifold-suction method of emasculating sweet clover flowers.

Following a suggestion offered by R. R. Drake, Associate Agronomist, Bureau of Agricultural Engineering, U. S. Dept. of Agriculture, an air-valve pet cock was inserted in the center of the intake manifold of a Model A Ford. Because it provides full suction from all cylinders, this location on the manifold is commonly used to connect a suction tube for the operation of a wind-shield wiper. One end of a quarter-inch pressure tube was fastened to the pet cock and a hypodermic needle was inserted in the other end of the tube. The

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[1] Contribution No. 17, the Fort Hays Branch of the Kansas Agricultural Experiment Station and the Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, cooperating.

[2] KIRK, L. E. Abnormal seed development in sweet clover species crosses—a new technique for emasculating sweet clover flowers. Sci. Agr., 10 : 321–327. 1930.

valve when open and with the engine running at idling speed developed slightly more suction than was obtained from local water pressure. The amount of suction may be regulated by varying the speed of the motor or the size of the opening in the valve.

Lack of uniformity in suction, caused by the motor, was overcome by inserting a 2,000-cc vacuum flask in the tube line between the pet cock and the needle. Like the expansion chamber in an aspirator pump, the flask took up the slack in the alternating suctions of the cylinders, and also provided a settling basin for the pollen. The flask was securely fastened to the fender of the car.

By means of this apparatus rapid and uniform emasculation of the flowers was accomplished in the field. It was possible to drive to within a few yards of any plant selected for emasculation. The method of procedure used in manipulating the flowers was the same as that described by Kirk, except that a hypodermic needle was substituted for a glass tube because the latter breaks easily.

Satisfactory results have been obtained at this station from limited use of this aspirator during 1933 and 1934. C. O. Grandfield, Assistant Agronomist, Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, adopted this method of emasculation and reports satisfactory results from its use in breeding alfalfa at Manhattan, Kansas.—D. A. SAVAGE, *Fort Hays Branch Experiment Station, Hays, Kansas.*

BOOK REVIEWS

SOIL DEFICIENCIES AND PLANT DISEASES

By G. V. Jacks and H. Scherbatoff. Harpenden, England: Imperial Bureau of Soil Science. Technical Communication No. 31. 46 pages. 1934. 2/ .

THIS Communication, which apparently has had very little notice in this country, is described by the editors as entirely non-critical and intended as a guide to the original literature. "The literature of the subject is vast, and the possibility of our having omitted some important papers or points of view cannot be overlooked," they state in a brief preface, and continue, "We have, however, collected together what have seemed to us to be the most relevant facts in the several hundred papers we have scanned. We have included fairly detailed descriptions of symptoms, and trust that these may sometimes be found useful in the diagnosis and treatment of diseases of doubtful origin."

The bibliography contains 367 entries. An unique feature of the publication is a table which precedes the bibliography listing the deficient elements, the main crops affected by deficiencies of each element, and the bibliographical references to papers dealing with each deficiency.

Through arrangements made between the publishers and the Chilean Nitrate Educational Bureau of 120 Broadway, New York City, copies of this Communication may be obtained from the latter as long as a limited supply lasts. (J. D. L.)

AN OUTLINE OF BIOMETRIC ANALYSIS

By Alan E. Treloar. Minneapolis, Minn.: Burgess Publishing Co., 65 pages of text and figs. 1935.

THIS is a combined text and notebook and is designed for "aiding students in grasping the fundamentals of courses in biometric analysis given by the author at the University of Minnesota." Only one side of each sheet is used for the text, the other side being left blank for notes. This publication will be welcomed by many research workers who desire to use biometry, but who either have a weak grasp of fundamentals or who wish to have a condensed text giving the various formulas and methods which frequently are scattered thru numerous publications.

There are few modern works that give such a condensed yet comprehensive account of what might be called Pearsonian biometry. The author has not included the work of R. A. Fisher and others on the analysis of variances and covariances but does give considerable space to the χ^2 criterion as developed by Fisher. The publication is worthy of a place in the library of experimentalists who are or should use biometrical methods in their research problems. (F. Z. H.)

THE BIOCHEMISTRY OF THE LIPIDS

By Henry B. Bull. Minneapolis, Minn.: Burgess Publishing Company. 127 pages, illus. 1935.

OUR rapidly changing ideas of the biochemical rôle of certain chemical compounds make the appearance of any up-to-date treatise most appreciated. This is especially true in the case of the lipids, which have not been dealt with in a comprehensive manner in recent years, except that the subject was touched upon by several articles in recent volumes of the *Annual Review of Biochemistry*. The lipids include the carotenes, vitamines A and D, and many other compounds which have been in the focus of scientific interest in recent years. A critical discussion of the modern developments in this field, therefore, is very desirable.

Although few agronomists will use this volume extensively, it will be of great help to many of them in supplying detailed information on this important group of components of the protoplasm. The book, which is based on Professor Bull's lectures at the University of Minnesota, well fulfills this need. It is unfortunate, however, that as in the case of some other books issued by the same publisher, there is no author and subject index to the volume. This fact curtails its usefulness as a reference book, the great number of references given in the volume making this lack of an index even more regrettable.

Bloor's classification is used in the grouping of the material. The main sections of the volume are entitled "Fatty Acids," "Soaps," "Alcohols," "Hydrocarbons," "Sterols," "Fats and Oils," Phospholipids," and "Glycolipids." The remainder of the volume is taken up by a discussion of "Emulsions" and of the "Physiology of Lipids." The latter deals mostly with animal physiology, but includes a short discussion on the "Lipid Physiology of Green Plants," which will be of interest to botanists and agronomists.

A large number of tables and especially the many graphs, together with a critical discussion of the information available in the literature, make this volume most interesting and useful to the student as well as to the research worker. (Z. I. K.)

AGRONOMIC AFFAIRS

PROGRAM OF THE SOIL BIOLOGY SUB-SECTION

THE program for the meetings of the Soil Biology Sub-Section of the Soils Section of the Society in Chicago in December has been provisionally outlined. The Friday morning session will be introduced by several brief papers on the experiences of those members who attended the Third Commission Sessions of the Third International Congress of Soil Science at Oxford, England. These papers will not conflict with, nor duplicate, those papers given at the Thursday afternoon general session of the Soils Section. During the remainder of the Friday morning session papers will be presented which relate to any field of soil biology other than that taken up in the Friday afternoon session.

The Friday afternoon session will be restricted to the consideration of the root-nodule bacteria and related problems on the inoculation of leguminous crops. A special invitation is extended to members of the Society who are connected with the commercial production of legume inoculation cultures to give short talks on some phase of their work.

No special requests for specific papers will be sent to members, but anyone wishing to present a paper before either session is urged to send a preliminary announcement not later than October 1 to the chairman of the Sub-Section, H. W. Batchelor, Agr. Exp. Station, Wooster, Ohio. This announcement should include the title of the paper, the probable length of time required for its presentation, and a brief statement of its contents.

PROGRAM OF THE CROPS SECTION AT CHICAGO

DR. R. D. LEWIS, Chairman of the Crops Section, announces the last call for papers to be presented at the annual meeting in December. Some suggestions for papers appeared on page 584 of the July number of the JOURNAL. These suggestions were not meant to exclude other worthy topics.

The program of the International Crop Improvement Association meeting in Chicago on December 4 will be printed with the program of the Society.

Titles, time required for presentation, and names of authors, as they are to appear on the program, should be sent to R. D. Lewis, Department of Agronomy, Ohio State University, Columbus, Ohio, by October 1.

TOBACCO FERTILIZER RECOMMENDATIONS FOR 1936

RECOMMENDATIONS for the fertilization of flue-cured, sun-cured, and shipping tobacco grown on average soils in Virginia, North Carolina, South Carolina, and Georgia during 1936 have been formulated by the Tobacco Research Committee composed of C. B. Williams, North Carolina, *Chairman;* T. B. Hutcheson, Virginia, *Secretary;* and H. W. Garner and J. E. McMurtrey of the Bureau of Plant Industry; E. M. Matthews, Virginia; H. P. Cooper, W. M. Lunn, and H. A. McGee, South Carolina; E. Y. Floyd, R. F. Poole.

L. G. Willis, and E. G. Moss, North Carolina; and E. C. Westbrook and J. M. Carr, Georgia.

Space will not permit a detailed publication of the recommendations of this Committee in the JOURNAL. The recommendations are available in mimeographed form, however, and may be obtained from the Chairman or the Secretary of the Committee.

DOCTOR CURTIS F. MARBUT

DR. C. F. Marbut, Director of the Soil Survey of the U. S. Dept. of Agriculture since 1910 and an international figure in the field of soil science, died of pneumonia in Harbin, Manchuria, on August 25 while enroute from the International Soil Congress in Oxford, England, to Peiping, China, where he was to undertake a study of the soils of China at the request of the Chinese government.

In addition to supervising the work of the Soil Survey of the U. S. Dept. of Agriculture which has mapped approximately 1,000,000,000 acres of land, or about half of the agricultural area of the United States, Dr. Marbut had also examined and classified the soils of every country of western Europe, except Spain. He was also familiar with the soils of Russia, had directed the classification of the soils of Africa, and had made a study of the soils of South America.

Dr. Marbut had but recently completed an inventory of the soil resources of the entire Nation soon to be published by the Department of Agriculture as part 3 of the *Atlas of American Agriculture*.

A more complete biographical sketch of Dr. Marbut's life and an appreciation of his work will appear in a later number of this JOURNAL.

NEWS ITEMS

DR. CHARLES E. KELLOGG has been named Principal Soil Scientist and Chief of the Soil Survey Division of the Bureau of Chemistry and Soils, U. S. Dept. of Agriculture, to fill the vacancy occasioned by the death of Dr. C. F. Marbut.

J. D. TINSLEY of Amarillo, Texas, died on August 5.

THE NINTH ANNUAL alfalfa seed conference of the Western Regional Section of the International Crop Improvement Association was held this year at the College of Agriculture, Madison, Wisconsin, on July 26 and 27. This is the first time that the representatives of the western alfalfa seed growers and seed certifying agencies have held their meeting in the middle west, thus affording a splendid opportunity for 75 producers, consumers, and distributers to discuss the many perplexing problems of the seed industry.

DR. LEROY POWERS resigned July 1, 1935, as Associate Professor of Agronomy and Plant Genetics, University of Minnesota, to accept a position as Geneticist with the Office of Horticultural Crops and Diseases, U. S. Dept. of Agriculture, with headquarters at Cheyenne, Wyoming.

DR. F. R. IMMER resigned as Associate Geneticist, Division of Sugar Plants, U. S. Dept. of Agriculture, on August 1, 1935, to become Associate Professor of Agronomy and Plant Genetics, University of Minnesota. Dr. Immer will devote half time to the Experiment Station as Statistical Adviser to members of the staff.

CARL BORGESON has been appointed instructor in Agronomy and Plant Genetics, University of Minnesota, and will take over the work of seed certification formerly cared for by A. D. Haedecke, who retired on July 1.

WILL M. MYERS was appointed Instructor in Agronomy and Plant Genetics, University of Minnesota, and will have charge of the cytological laboratory of the Division.

S. P. SWENSON, W. W. BROOKINS, and KARL MANKE have accepted research assistantships in the Division of Agronomy and Plant Genetics, University of Minnesota.

ACCORDING to a recent note in *Science*, J. M. Westgate, Director of the Hawaii Agricultural Experiment Station since 1915, has resigned to become professor of tropical agriculture in the University of Hawaii. He is to be succeeded by Dr. O. C. Magistad, formerly chemist for the Pineapple Experiment Station.

Science also reports that R. L. Pendleton, professor of soil technology and head of the Department of Soils, College of Agriculture, University of the Philippines, at Los Banos, has retired to accept a position as soil technologist and agriculturist to the Department of Agriculture of the Siamese Government, with headquarters in Bangkok, Siam.

DR. D. F. JONES, head of the Department of Genetics, Connecticut Agricultural Experiment Station, has been granted leave of absence beginning September 1, for work at the California Institute of Technology at Pasadena.

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WHAT IS A WEED?[1]

A. J. PIETERS[2]

AT the present time a great deal of interest centers in weeds, especially in the control of some of the most obnoxious ones. The question arises, therefore, what is a weed? Perhaps the question is more or less academic, since so far as the serious weeds are concerned at least, there is no dispute as to what they are and that they are serious weeds.

Agronomists should, however, be able to define their concepts as comprehensively and accurately as possible and hence it may not be out of place to renew the inquiry as to the proper definition of a weed. Is it possible to frame a definition at once inclusive and exclusive? The brief discussion herewith covers an attempt to analyze the definitions current or proposed; to point out in what particular they are unsatisfactory and to raise the question whether a better definition can be framed.

The late Dr. Beal, of blessed memory, was the one who offered the definition which has been pretty generally accepted. He said a weed was a plant out of place. While this definition has a great deal to recommend it, it has always seemed to the writer somewhat unsatisfactory. The term "weed" is an odious one and carries with it inevitably the idea of something evil, of something that does harm and should be destroyed. Dr. Beal's definition makes the matter depend on where the plant is found and according to that definition the same plant might at one time be a weed and at another, not a weed. Buckhorn, thistle, and crabgrass would, under this definition, be weeds when found in cultivated fields but when growing along the roadside or in waste places, they would not be weeds. On the other hand, red clover in a garden would be a weed. Except as a concept of the human mind no wild plant is out of place. It is merely a part of the general scheme of nature.

Dr. Beal's definition depends on the place where a plant is found, not upon any character inherent in the plant.

The writer has been very much interested in speculating on this point because in his own garden white clover, bluegrass, and the American elm make more trouble than any other plants. In this

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[1] Contribution from the Division of Forage Crops and Diseases, U. S. Dept. of Agriculture, Washington, D. C. Received for publication August 19, 1935.

[2] Principal Agronomist in charge.

garden are two large elm trees which bloom abundantly every spring and in a few weeks after blooming the lawn and the garden are covered with young elm seedlings. These are certainly out of place, and in the hardy herbaceous border they make a great deal of trouble because each seedling must be picked out individually from between the clumps of hardy perennials. Still, the American elm is certainly not a weed.

It is so with white clover and bluegrass. The more the garden is fertilized the more white clover and bluegrass creep in among the hardy perennials, and it is a constant fight to keep these invaders subdued. At the same time, it is doubtful whether any agronomist would commonly think of these plants as weeds, in spite of the fact that they are decidedly out of place in the hardy border and cause the gardener a great deal of trouble.

Webster defines a weed as "any plant growing in cultivated ground to the injury of the crop or desired vegetation or to the disfigurement of the place; an unsightly, useless or injurious plant." The great majority of plant species are useless to man, most are unsightly at some stage, and there are injurious plants, as some poisonous ones, that never invade cultivated fields. In the corn belt, and elsewhere in the humid East, Kentucky bluegrass grows among alfalfa to the detriment of that crop and if this is called a weed, we are back to Beal's definition and then a plant may be a weed one place and not in another.

The Oxford dictionary says that a weed is "a herbaceous plant not valued for use or beauty, growing wild and rank, and regarded as cumbering the ground or hindering the growth of superior vegetation." Under this definition, would Johnson grass be a weed? It certainly is valued as a hay plant, but it is equally true that under some circumstances it hinders the growth of superior vegetation.

Bailey in his *Cyclopeadia of Horticulture* frankly states that a plant may be a weed in one place and not in another, and continues: "There are of course, species that are habitual weeds; but in their wild state where they do not intrude on cultivated areas, they can scarcely be called weeds." It is clear that Dr. Bailey does not think it possible to define a weed except in terms of location.

In U. S. Dept. of Agriculture Farmers' Bulletin 660 (1915), entitled "Weeds: How to Control Them," by H. R. Cox, the definition of a weed suggested by J. Sidney Cates, is "a wild plant that has the habit of intruding where not wanted." This definition carries the same thought as that expressed by Dr. Beal but goes further and attributes a "habit of intruding" to the plant. But here, too, it may be noted that Kentucky bluegrass has, in the corn belt, the habit of intruding on alfalfa fields.

None of the definitions so far considered get away from the thought that a plant may be a weed or not a weed, depending on where it is. According to these definitions valuable plants like white clover or Kentucky bluegrass may be called weeds, while buckhorn, Canada thistle, and others growing in waste places would not be weeds.

The underlying thought in the use of the word "weed" by the people for more than a thousand years has been that of an undesirable plant; not one unwanted here or there, but one fundamentally bad. Such a plant as a thistle was a weed. Such a plant as white clover, well known hundreds of years ago was not called a weed and, of course, Kentucky bluegrass and Johnson grass were not known. Established usage is the foundation of usage in the English language, but new plants not known to the English of the 10th and 11th centuries and new agricultural practices may make it necessary to broaden our concept of what a weed is.

The Forest Service classes all plants on the range as "grasses," "grass-like plants," "trees and shrubs," and "weeds," the latter term covering all other herbs. This is obviously a definition of convenience and without any bearing on the usefulness of the species. It would be better usage to substitute "forbs" for weeds.

Is it possible to get away from this anomalous situation and make a definition that will exclude from the opprobrious term "weed," plants that sometimes grow where they are not wanted? Perhaps this is not possible but the writer would like to have agronomists consider this question anew and as a contribution to the discussion suggests that "a weed is a plant whose potentialities for harm are greater than its potentialities for good." According to this definition, white clover would not be a weed even though it is annoying at times, because its extreme usefulness far outweighs the little harm it does. On the other hand, the Canada thistle would always be a weed no matter where it was because it does a great deal of harm and no good. There will, of course, be some plants as Johnson grass in the South on which there might be a dispute. While Johnson grass is an unmitigated nuisance in cultivated fields, it does provide quite a bit of grazing and in some parts of the South it provides some hay. It is quite certain, however, that farmers would gladly dispense with Johnson grass for hay if there were any way to destroy it utterly; it does more harm than good.

The writer realizes that the application of the definition offered depends on our knowledge of a given plant. This may be incomplete, but so soon as the characteristics of a plant become well known it should be possible to place it in its proper classification, and a weed would be a weed even though temporarily useful to man; a plant like white clover would never be called a weed though it might be temporarily annoying.

Attention is called once more to the fact that in long established usage the term "weed" did not mean "a plant out of place" but meant an injurious plant with no good in it. The term "a plant out of place" is a catchy one but does not conform to ancient usage and permits the inclusion of useful plants among weeds because the useful plants sometimes grow where not wanted.

Possibly a modification of the definition in Farmers' Bulletin 660 might meet the case and we might define a weed as "a plant that does more harm than good and has the habit of intruding where not wanted."

SEED PRODUCTION STUDIES WITH LEGUMES IN HAWAII[1]

C. P. WILSIE[2]

WHILE the use of legumes for green manuring and forage has received a great deal of attention both in the temperate zones and in the tropics, little information is available on the seed production possibilities of many of the species that show promise in tropical and sub-tropical agriculture. Seed production becomes important whenever extensive acreages are planted and particularly when a new variety or species is disseminated to farmers and planters.

LITERATURE CITED

In a study of the agronomic possibilities of the velvet bean (*Stizolobium deeringianum*) in Florida, Scott (4)[3] obtained seed yields of from 20 to 48 bushels per acre using different varieties. A perfect stand seemed to be the most important factor in the determination of yield due particularly to the spreading nature of the plants.

Kennedy and Madson (2) reported on seed production experiments with the mat or moth bean (*Phaseolus aconitifolius*) in California. In a spacing experiment at Kearney Park yields of from 1,557 to 2,614 pounds per acre were obtained. At the University Farm, Davis, yields averaged 715 pounds per acre. This species is an important food crop in India but has never gained much favor in the United States.

Seed yields of several Crotalaria species have been reported by McKee (3). At McNeill, Mississippi, in 1927, *Crotalaria spectabilis* yielded at the rate of 890 to 992 pounds per acre. At Gainesville, Florida, seed yields were much lower for four Crotalaria species, ranging from 16.5 to 657 pounds per acre. Timson (6) stated that sunn hemp (*Crotalaria juncea*) at the Salisbury Experiment Station usually yields from 400 to 800 pounds of seed per acre. The yields are uncertain due to the presence of a Vermicularia blight which sometimes severely attacks the crop. No data are given on the effect of spacing, but for seed production sunn hemp is usually planted in rows 15 to 20 inches apart using about 20 pounds of seed per acre.

Shaw and Khan (5) have reported seed production tests with the pigeon pea (*Cajanus indicus*) and the gram (*Cicer arietinum*). Pigeon pea yields usually range from 600 to 1,800 pounds per acre and the yields of various gram types range from 400 to 1,000 pounds per acre.

In considering alfalfa (*Medicago sativa*), there is a great deal of uncertainty and variability in seed production. Hughes and Henson (1), in generalizing on seed yields in the United States, say that in the corn belt the yields run from 2 to 3 bushels per acre and in the arid west 4 to 6 bushels per acre are common.

EXPERIMENTAL METHODS

In recent years a large number of legumes have been introduced to Hawaii by the Hawaii Agricultural Experiment Station and other local research agencies.

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[1] Contribution from the Hawaii Agricultural Experiment Station, University of Hawaii, Honolulu, T. H. Received for publication August 15, 1935.

[2] Agronomist. The author is indebted to Makoto Takahashi, Frank Mercado, and H. F. Willey for assistance in the collection of the field data.

[3] Figures in parenthesis refer to "Literature Cited," p. 790.

Several of these are promising for green manuring and some are desirable for forage. During 1930 to 1933 the seed production possibilities of these species were studied in carefully spaced plantings. Uniform row spacings of 5 feet were used, the object being to insure plenty of space for plant development with little competitive effect from adjacent rows. Within the row three spacings were used, plants being 6, 12, and 24 inches apart, respectively. All plantings were made early in the spring (February 8 to 15) and notes were taken on germination, growth habits, flowering, and seed setting. Seed was harvested whenever ripe and in some species with uneven maturity of pods, several successive harvests were made until the whole crop was finished for that season.

Among the legumes studied some matured seed in about 3 months while others required nearly a year to complete their growth cycle. The yields as obtained in this experiment are based on the production of 10 plants at each spacing. In most cases individual plant yields were recorded, but due to the detail involved only yields per acre will be given. The experiments were carried on during two successive years, 1930 and 1931, and average yields for the two years are given in Table 1.

While the data would undoubtedly be more reliable had the plats been laid out with a number of replications and still closer spacings used, it is believed that the results obtained are worthy of publication because of the accuracy of the space planting and individual plant harvesting methods used. The plats were located at the Pensacola Street Station in Honolulu at an elevation of about 85 feet above sea level. The average rainfall in that vicinity is 30 to 35 inches per year.

RESULTS

The results given in Table 1 indicate excellent possibilities for seed production with most of the species tested. The closest spacing used (6 inches) gave the highest yield in most cases. In some instances still higher yields would probably have been obtained with a closer spacing of plants than was used in this experiment. It is fortunate that among those species which offer greatest promise as green manuring crops, *Crotalaria juncea*, *Crotalaria anagyroides*, and velvet beans, all have favorable seeding habits under Honolulu conditions.

SEED YIELDS OF THE BLUE LUPINE

At an elevation of 2,100 feet at the Haleakala Substation on the island of Maui a detailed spacing experiment was conducted with the blue lupine (*Lupinus augustifolius*). Of the many legumes tested at this elevation, the blue lupine has proved to be the most successful for green manuring. Rows were planted 5 feet apart with hills spaced 6, 12, 24, 36, and 48 inches in the row. The number of plants per hill was also varied from one to five thus giving a comparison of 25 different types of spacing. The seed yields obtained are recorded in Table 2. The effect of spacing upon the yield per plant and upon the yield per acre is given.

As the number of plants per acre increased, the yield per plant decreased. This seems to be generally true in all of the five planting groups differing in number of plants per hill. In yields per acre there seems to be a direct positive correlation between the number of plants per acre and total acre yield. This relation would hold only for a

TABLE I.—*Seed yields of legumes, two years' results.*

Species	Accession No.	Months to mature	Spacing of plants within the row (rows 5 feet apart), in.	Yield per acre, lbs.
Crotalaria usaramoensis	2303	7	6	915
			12	1,154
			24	816
Crotalaria spectabilis	2301	5	6	1,050
			12	782
			24	560
Crotalaria juncea (sunn hemp)	2296	5–6	6	938
			12	1,074
			24	596
Crotalaria anagyroides	2293	9	6	1,102
			12	784
			24	510
Crotalaria grantiana	2305	8	6	2,830
			12	1,950
			24	1,586
Phaseolus mungo (urd bean)	2309	4	6	1,136
			12	991
			24	632
Phaseolus lathyroides (wild pea bean)	2311	4	6	493
			12	264
			24	123
Cicer arietinum (gram)	2319	4	6	403
			12	381
			24	254
Phaseolus aconitifolius (moth bean)	2315	3–4	6	934
			12	730
			24	393
Cassia occidentale	2324	8	6	5,794
			12	2,657
			24	2,853
Canavalia ensiformis (jack bean)	2328	7	6	3,528
			12	3,071
			24	2,146
Stizolobium deeringianum (velvet bean)	2333	7	6	2,439
			12	2,004
			24	1,797
Stizolobium deeringianum (velvet bean)	2334	7–8	6	3,136
			12	2,526
			24	1,971

TABLE 1.—*Continued.*

Species	Accession No.	Months to mature	Spacing of plants within the row (rows 5 feet apart), in.	Yield per acre, lbs.
Melilotus alba annua (hubam)	2337	6–7	6	1,699
			12	1,612
			24	1,345
Desmodium uncinatum (Spanish clover)	2340	4–5	6	518
			12	394
			24	282
Medicago sativa (Chilean alfalfa)	2341	5	6	722
			12	698
			24	650
Medicago sativa (hairy Peruvian alfalfa)	2342	5	6	864
			12	738
			24	556
Teprosia candida	2345	13	6	1,090
			12	1,046
			24	458
Tephrosia noctiflora	2346	8	6	3,245
			12	3,006
			24	1,802
Leucaena glauca (ekoa)	2348	10	6	5,488
			12	3,006
			24	2,146
Phaseolus calcaratus (rice bean)	2354	3	6	328
			12	202
			24	132

certain series of values, beyond which further increases in plants per acre would result in a decrease in yields.

SPACING EXPERIMENTS WITH PIGEON PEAS

The effect of spacing on the yield of "Strain D" variety of pigeon peas (*Caianus indicus*) was studied at the University Farm, Honolulu. This variety has proved to be extremely valuable for forage, green manuring, and, to some extent, human food and is widely scattered at low and medium elevations in various parts of the territory. Using a row spacing of 5 feet, hills were spaced 2½ feet, 5 feet, and 7½ feet, respectively. The number of plants per hill varied from one to four. Two crops of seed were harvested from these plats and the total yields given in Table 3. There were four replications of plats in this experiment.

TABLE 2.—*Effect of spacing on seed yield of blue lupine* (*L. angustifolius*).

Spacing of hills within the row (rows 5 feet apart), in.	Plants per acre	Yield per plant, ozs.	Yield per acre, lbs.
1 Plant per Hill			
6	17,424	1.59	1,738
12	8,712	2.77	1,511
24	4,356	3.98	1,085
36	2,904	4.33	786
48	2,178	3.64	496
2 Plants per Hill			
6	34,848	0.84	1,837
12	17,424	1.11	1,211
24	8,712	1.99	1,086
36	5,808	2.05	744
48	4,356	1.85	505
3 Plants per Hill			
6	52,272	0.66	2,154
12	26,136	1.00	1,644
24	13,068	1.67	1,367
36	8,712	2.03	1,110
48	6,534	1.56	637
4 Plants per Hill			
6	69,696	0.42	1,846
12	34,848	0.73	1,600
24	17,424	1.23	1,342
36	11,616	1.54	1,118
48	8,712	1.28	698
5 Plants per Hill			
6	87,120	0.47	2,559
12	43,560	0.59	1,606
24	21,780	0.96	1,308
36	14,520	1.14	1,077
48	10,890	1.33	909

TABLE 3.—*Effect of spacing on yield in the pigeon pea* (*Cajanus indicus*).

Spacing of hills, ft.	No. of plants per hill	No. of plants per acre	Yield per acre in two crops, lbs.	Mean yield per acre for each spacing series, lbs.
5 x 2½	1	3,485	4,016±10%*	3,777±189*
	2	6,970	3,406	
	3	10,455	3,697	
	4	13,940	3,988	
5 x 5	1	1,742	3,611	3,724±186
	2	3,485	3,740	
	3	5,227	3,304	
	4	6,970	4,243	
5 x 7½	1	1,162	3,941	4,195±210
	2	2,323	3,817	
	3	3,485	4,432	
	4	4,646	4,589	

*Standard error.

The results indicate that spacing 5 x 7½ feet is slightly the best, though statistical analysis shows this difference to be insignificant. There is also very little difference in yield whether there are one or four plants per hill. The growth habit of the pigeon pea is such that it readily adapts itself to the space available (Fig. 1). This seems to be true within rather wide limits of spacing for there are more than 10 times as many plants per acre with four plants per hill at the 5 x 2½ foot spacing as there are with one plant per hill at the 5 x 7½ foot spacing; yet the yields are nearly the same.

When still wider spacings are used, the yield gradually falls off as may be shown in Table 4. This experiment was laid out in a different field, lower in fertility, and one crop only was harvested. Yields, therefore, should be at least doubled to compare with those in Table 3.

For seed production purposes under conditions similar to those which obtained in these experiments the use of more than 4,000 to 5,000 plants per acre is probably not justified. Under less favorable conditions, when the plant growth is much smaller, a higher rate of seeding would be more desirable.

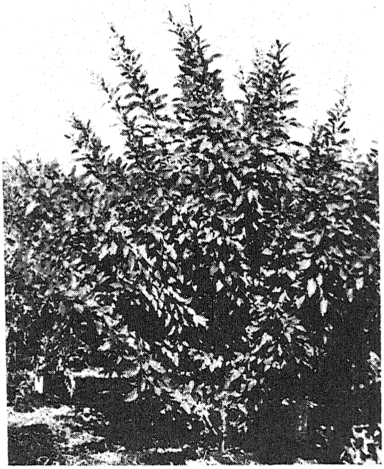

FIG. 1.—A single plant of pigeon pea (*Cajanus indicus* Spreng.), showing profuse branching when allowed adequate space for development.

SUMMARY

Seed yields are reported for a number of green manuring and forage legumes grown at different spacings under Hawaiian conditions. The possibilities for seed production are very favorable for most of the legumes tested. A fairly close spacing of plants gave better results with most species than a wide spacing.

A detailed spacing experiment with the blue lupine grown at 2,100 feet elevation is reported. With the blue lupine the hill spacing of 6 inches was better than any wider spacing. This held true regardless of the number of plants per hill. The use of three, four, or five plants per hill (considering each spacing series) gave slightly higher yields than one or two plants per hill. Increases in yield resulted from an increase in the number of plants per acre until about 87,000 plants were used.

Seed production with the pigeon pea was studied at low elevations in Honolulu. It was found that within rather wide limits a change in spacing had but little effect on yield. This species seems to possess the remarkable ability to utilize the space offered. If planted thickly the stems were slender and grew straight up with little branching, while if given adequate space the plants became very bushy with a great deal of branching. This adaptability resulted in yields that were approximately the same when the number of plants per acre was varied from 2,000 to 14,000.

TABLE 4.—*Pigeon pea yields under widely differing spacings but with only one plant per hill.*

Spacing, ft.	Plants per acre	Yield per acre (one crop only), lbs.
5 x 1	8,712	1,732
5 x 2	4,356	1,509
5 x 3	2,904	1,297
5 x 4	2,178	1,200
5 x 5	1,742	1,067
7½ x 1	5,808	1,142
7½ x 2	2,904	1,168
7½ x 3	1,936	845
7½ x 4	1,452	876
7½ x 5	1,162	770
10 x 2½	1,742	784
10 x 5	871	785
10 x 7½	581	655
10 x 10	436	512

Differences in the fertility level, soil moisture, and seasonal conditions undoubtedly have a great influence on the yield of seed under different spacing treatments. It is not presumed that the data presented give precisely the best spacing to use with each of the legumes considered. It is believed, however, that the results do present a reasonably satisfactory basis for the adoption of spacing recommendations when grown under conditions similar to those found in Hawaii.

LITERATURE CITED

1. HUGHES, H. D., and HENSON, E. R. Crop Production. New York : Macmillan Co. 1930.
2. KENNEDY, P. B., and MADSON, B. A. The mat bean (*Phaseolus aconitifolius*). Calif. Agr. Exp. Sta. Bul. 396 : 14 and 31. 1925.
3. McKEE, ROLAND. Crotalaria, a new legume for the South. U. S. D. A. Cir. 137 : 14. 1931.
4. SCOTT, JOHN. Velvet bean varieties. Fla. Agr. Exp. Sta. Bul. 152 : 229–230. 1919.
5. SHAW, F. J. F., and KHAN, ABDUR RAHMAN. Reports of the Imperial Economic Botanist. Agr. Res. Inst., Pusa, Sci. Rpts. 1928–29, 1929–30, 1930–31.
6. TIMSON, S. D. Sunn hemp (*Crotalaria juncea*). Rhodesia Agr. Jour., 26 : 668–682. 1929.

THE RHIZOMES OF CERTAIN SPECIES OF GRASSES[1]

MORGAN W. EVANS AND J. E. ELY[2]

ACCORDING to the earlier use of the term, *rhizome* meant the procumbent rooting stems of any plant, whether they grow on or beneath the surface of the soil (4, p. 882).[3] According to the most recent usage, which is adopted in this discussion of grasses, the term rhizome refers only to rooting stems which grow beneath the surface of the soil, although in some cases they may originate just above the surface. Rooting stems growing above the surface of the soil are called *stolons*.

All rhizomes have certain common characteristics. The investigations here described, however, show that the rhizomes of grass species also differ in respect to their habits of growth.

In four of the five species studied, i. e., Canada bluegrass (*Poa compressa L.*), quackgrass (*Agropyron repens L.*) (Beau.) redtop (*Agrostis alba L.*), and reed canary grass (*Phalaris arundinacea L.*), the rhizomes originate almost entirely below the surface of the soil from buds at the nodes of other rhizomes. On the other hand, plants of Kentucky bluegrass (*Poa pratensis L.*) very commonly, though not always, produce rhizomes from buds in the axils of fully developed leaves on above-ground shoots. Usually, these buds are just below the surface of the soil, but not infrequently they grow from buds slightly above it. Although a rhizome of Kentucky bluegrass may originate from a bud just above the surface of the soil, it soon turns downward and completes its development below the surface.

In 1932 and in 1933 during the first part of each month from spring until fall, examinations were made of plants of the five species of grasses previously mentioned for the purpose of obtaining records of the development of the rhizomes. The plants were all taken from cultivated row plats 4.0 x 3.3 feet apart to which they had been transplanted on May 18, 1931. The culms of these plants were not cut during the entire season. Each month the soil was washed away from two or three plants, usually the latter number, of each species and records made of the number and length of the rhizomes, and of the number of internodes of which each was composed.

Since the plants were continually increasing in size, by the late spring of 1933 they had become so large that more time was required for making records of whole plants than was available. Accordingly, from May 1933 until the final records were made in the fall of that year, each plant was divided, as accurately as possible, and records

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[1] Contribution from the Timothy Breeding Station, North Ridgeville, Ohio, conducted cooperatively by the Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, and the Department of Agronomy, Ohio Agricultural Experiment Station, Wooster, Ohio. Received for publication July 19, 1935.

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[3] Figures in parenthesis refer to "Literature Cited," p. 797.

made from either half or quarter plants. The records for the whole plant were then derived from the data obtained from the fractional part.

TIME RHIZOMES DEVELOP

Table 1 shows that the number of rhizomes developed is not the same at different times of the year. At certain seasons they form in greater numbers than at other times, as there are certain seasons when different phases of development of above-ground shoots occur. These periods of development vary to some extent for different species.

TABLE 1.—*Average number of new rhizomes per plant having either one or two internodes each in different months in 1932 and 1933 on plants of different species, transplanted on May 18, 1931.*

Month	Canada bluegrass	Kentucky bluegrass	Quack-grass	Red-top	Reed canary-grass
			1932		
June....	9.0	15.5	25.0	1.5	21.0
July....	4.3	18.3	8.6	28.6	9.0
Aug.....	44.3	3.3	2.0	1.3	6.6
Sept....	8.6	0.3	1.3	7.0	2.0
Oct.....	19.6	2.3	2.3	7.6	1.3
Nov.....	29.0	3.0	1.3	4.6	0.6
			1933		
Apr.....	0.3	0.0	0.7	0.0	0.0
May....	3.3	0.3	38.0	0.3	7.3
June....	2.7	5.3	16.0	3.3	11.0
July....	0.3	2.0	5.0	3.0	4.5
Aug.....	218.7	21.0	49.7	8.7	6.0
Sept....	187.5	6.0	16.5	2.0	2.0
Oct.....	13.0	0.5	20.5	1.0	2.0

The numbers of rhizomes which developed during different months may have been affected to some extent by the amount of precipitation. In 1933, especially during the late spring and summer, there was a marked deficiency in the rainfall. Table 2 shows the monthly and the annual rainfall in 1932 and in 1933, and also the mean for the years 1871 to 1934, at the U. S. Weather Bureau Station at Cleveland, Ohio, which is located approximately 20 miles from and is at about the same altitude as the Timothy Breeding Station at North Ridgeville, Ohio, where these studies were made.

TABLE 2.—*Monthly and annual precipitation in 1932 and 1933, and the mean for the years 1871 to 1934, in inches, at the U. S. Weather Bureau Station, Cleveland, Ohio.*

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1932....	3.46	1.10	3.39	2.09	3.71	1.88	2.42	4.31	1.45	3.06	2.63	3.77	33.27
1933....	1.40	1.99	3.51	2.42	2.86	0.39	1.26	1.98	2.73	0.97	3.06	1.60	24.17
Mean, 1871–1934	2.59	2.43	2.76	2.48	3.06	3.26	3.55	2.86	3.26	2.78	2.60	2.39	34.02

RELATIVE TIME OF DEVELOPMENT OF NEW RHIZOMES AND OF NEW ABOVE-GROUND SHOOTS

The data in Table 1 show that, generally, new rhizomes are developing in the greatest numbers during June, July, August, and early September. Conversely, above-ground shoots develop in relatively small numbers during the midsummer months. In the latitude of northern Ohio, they appear in the greatest numbers from about August until the close of the growing season, and continue to develop during April and early May in the following season. As the numbers of new rhizomes again increase after this time, there is a decrease in the numbers of new above-ground shoots. Although the seasons for the greatest numerical development of rhizomes and of above-ground shoots overlap to some extent, they do not coincide.

DURATION OF TIME RHIZOMES CONTINUE GROWTH

During the period from June 2 to 13, 1932, a large number of young rhizomes on plants of different species of grass, each rhizome having from one to four elongated internodes, were marked with copper wire and the soil replaced over them. Later, an examination was made of 10 of these marked rhizomes of each species distributed on several different plants on each one of two dates, July 12 to 13, and again on August 9.

The records show considerable variation in the duration of growth of rhizomes of different species. On August 9, rhizomes on plants of Canada bluegrass and reed canarygrass, which had begun their growth in late May or early June, had all terminated as above-ground shoots. On the plants of quackgrass, all excepting 1 of the 20 rhizomes examined in July and August were continuing their growth up to that time as rhizomes. About one-half or a little more of the rhizomes of Kentucky bluegrass and of redtop first observed in June had terminated as above-ground shoots during July and August.

Rhizomes which began their development in late summer or fall continued growth for a longer time. Examinations made at the beginning of the growing season early in the spring of plants of all species have shown large numbers of rhizomes which began their growth in the preceding year. During the spring, the tips of many of the branches which had hitherto grown as rhizomes became transformed into above-ground shoots.

MODES OF BRANCHING

The variety of forms of rhizome systems of grasses may be compared with the great variety of forms of their inflorescences. The differences in the rhizome systems, like the differences in the inflorescences, is due very largely to variations in the manner of branching.

Three types of branching of rhizomes occurring in grasses are represented among the species used in this study.

The type of rhizome development illustrated by Canada bluegrass is comparatively simple. Rhizome branches grow from nodes on the rhizomes producing them, often at fairly regular distances apart. This process continues until the terminal bud of the older rhizome finally develops into an above-ground shoot. By this time new branches may be growing from the first set of rhizome branches.

In general, the branching systems of the rhizomes of quackgrass (5) and of redtop resemble that of Canada bluegrass. In respect to details, however, such as the length and diameter of the rhizomes, length of the internodes, and the frequency at which new branches develop, there is quite wide variation among the plants of these species.

The growing habits of the plants of Canada bluegrass and of Kentucky bluegrass differ in various ways (3). One of these differences is the manner in which the rhizomes originate.

As stated, new rhizomes on plants of Canada bluegrass usually grow from buds at nodes on other rhizomes beneath the surface of the soil. Although some of the branches develop on plants of Kentucky bluegrass in the way described for Canada bluegrass, a large proportion of the new rhizomes develop from nodes between non-elongated internodes at the base of the above-ground shoots. The number of branch rhizomes growing directly from the base of a single shoot does not often exceed two or three and may be less. From other buds in the axils of leaves at the base of the terminal above-ground shoot, however, new lateral above-ground shoots grow, and from these secondary shoots still other newer branches may develop, all of which forms a more or less dense tuft of above-ground stems.

Not infrequently, on a rhizome of Kentucky bluegrass the internodes near its tip may fail to become elongated. From several of the nodes connected by these non-elongated internodes, branch rhizomes may grow in the form of a tuft below the surface of the soil in a way somewhat similar to that in which a tuft of above-ground stems develop.

The third, somewhat different, type of systems of rhizomes may be illustrated by those of reed canarygrass. In the plants of this species each rhizome grows for a time from the bud from which it originated, then, as in other species, the terminal bud grows upward toward the surface of the soil and produces an above-ground shoot. A new rhizome develops and grows, very commonly in the same direction as the original one, from a bud near the tip of the older rhizome or from one in the axil of a leaf at the base of the above-ground shoot which develops from it. The second one may also terminate in an above-ground shoot, and a third rhizome develop and grow in the same general direction as the older ones. Successive rhizomes may then develop in this way. Although very frequently only one branch rhizome develops near the tip of an older one, yet sometimes several form, and the direction of growth of some or even of all of them may be different from that of the parent rhizome.

RATE AT WHICH PLANTS SPREAD BY MEANS OF RHIZOMES

The area over which a grass plant spreads within a given length of time depends upon a number of factors (2, p. 8). Some of these conditions are soil and climate or weather; others are inherent in the plants themselves, such as the lengths to which the rhizomes grow and the frequency at which new branch rhizomes appear.

The rates at which different plants of the same species spread outward over the adjoining area also may differ greatly (1).

The average area occupied by three plants, of each of several species of grass examined from April 17 to May 9, 1932, as measured by the minimum and the maximum diameters, is shown in Table 3. This table gives information as to the lengths of the rhizomes, the lengths and numbers of the internodes of which they are composed, and the percentage of nodes from which branches had developed.

At the time of transplanting on May 18, 1931, each plant consisted of a single original rhizome having several elongated internodes and terminated in an above-ground shoot. The new rhizomes developing from the original may be referred to as the primary branches and the rhizomes originating from the primary branches as the secondary ones. The rhizomes described represent these secondary branches, as shown in Table 4.

TABLE 3.—*Growth made up to April 17 to May 9, 1932, by plants from single rhizomes which had been planted May 18, 1931.*

Species	Average maximum and minimum diameter of plant, inches	Length in inches per			Average number per rhizome of elongated internodes	Percentage of elongated internodes with branch at distal node
		Rhizome		Internode of rhizome, average		
		Average	Maximum			
Canada bluegrass	10.7x13.0	2.32	7.9	0.53	4.4	19.7
Kentucky bluegrass	7.3x10.0	3.60	7.9	0.39	9.25	10.0
Quackgrass	18.7x31.3	6.60	22.6	0.59	11.2	5.1
Redtop	5.7x 9.7	1.55	6.7	0.31	5.0	10.5
Reed canarygrass	11.3x13.7	1.56	4.3	0.23	6.81	13.9

TABLE 4.—*Multiple branching of rhizomes in different species of grasses.*

Species	Average total number of rhizomes representing branches of order							
	A	B	C	D	E	F	G	H
Canada bluegrass	3.0	10.3	9.0	3.3	2.0	0.7	0.0	—
Kentucky bluegrass	4.3	9.3	8.7	2.7	0.0	—	—	—
Quackgrass	5.0	15.7	9.0	0.0	—	—	—	—
Redtop	5.3	7.7	4.0	0.0	—	—	—	—
Reed canarygrass	4.3	12.0	11.3	8.7	9.7	4.0	0.3	0.0

Table 3 shows the extent of the direct relationship between the lengths of the individual rhizomes and the area the plants occupy within a given time. Thus, the lengths of the rhizomes of quackgrass, which spreads more rapidly than any other species studied, are greater than the lengths of the rhizomes of any of the other grasses. The plants of Kentucky bluegrass have rhizomes with a greater average length than those of the plants of either Canada bluegrass or reed canarygrass, yet the plants of Kentucky bluegrass spread less rapidly than the plants of either one of the other two species.

The explanation for the more rapid growth of the plants of Canada bluegrass and of reed canarygrass than the plants of Kentucky bluegrass may be found in Table 4. From the time the plants were transplanted on May 18, 1931, until April 17 to May 9, 1932, rhizomes of the 4th order of branching had developed on plants of Kentucky bluegrass, of the 6th order on plants of Canada bluegrass, and of the 7th order on plants of reed canarygrass. The more frequent appearance of new rhizomes on the plants of the two latter species more than compensates for their shorter rhizomes as compared with those of Kentucky bluegrass.

The length to which rhizomes grow is partially dependent upon the length of the internodes of which they are composed. The rhizomes of quackgrass, which are longer than those of any other species here described, are composed of internodes longer than those of any of the other grasses.

SUMMARY

The rhizomes of grasses, as well as of other plants, include those forms of elongated rooting stems which grow beneath the surface of the soil.

Both rhizomes and above-ground shoots develop, to a limited extent, at all times when weather conditions are favorable for growth. The new shoots of each type develop in the greatest numbers at fairly definite seasons which overlap to some extent but which do not coincide. In the latitude of northern Ohio, new rhizomes appear in the greatest numbers on plants of the species studied, chiefly during June, July, August, and early September. New above-ground shoots, on the other hand, develop in the greatest numbers from August or September until the close of the growing season, and during April and early May.

A great deal of variation occurs in the way in which rhizomes develop in different species of grasses. In some species, as in Canada bluegrass, the secondary and later rhizomes originate from buds at nodes on older rhizomes at more or less regular intervals. In other species, as Kentucky bluegrass, a very large proportion of rhizomes originate from buds at the bases of above-ground shoots. Rhizomes originating in this way at first grow downward and penetrate the soil, then grow horizontally beneath its surface. The variations in the manner of the origin and the later development of rhizomes on plants of different species of grasses, like the variations in the manner of branching in their inflorescence, result in different types of rhizome systems.

The rate at which a rhizomatious plant spreads depends partly upon external conditions, and partly upon conditions inherent in the plant. The lengths to which the rhizomes grow and the frequency with which new ones develop determine the spread of the area occupied.

LITERATURE CITED

1. Derick, R. A. An index to selection work with awnless brome grass. Sci. Agr., 8:556–559. 1928.
2. Evans, M. W. The life history of timothy. U. S. D. A. Dept. Bul. 1450. 1927.
3. ———— and Ely, J. E. Usefulness of Kentucky bluegrass and Canada bluegrass in turfs as affected by their habits of growth. Bul. U. S. Golf. Assoc., Green Sect., 13:140–143. 1933.
4. Gray, Asa. Gray's New Manual of Botany. Ed. 7. 1908.
5. Kephart, L. W. Quackgrass. U. S. D. A. Farmers' Bul. 1307. 1931.

VARIABILITY IN MEASUREMENTS OF HEIGHT AND WIDTH OF MARKET GARDEN PLANTS[1]

Donald R. Willard and John B. Smith[2]

IN a recent comparison of the growth of vegetable crops from single and fractional applications of nitrogen,[3] the height and width of several crops were measured at intervals. The results of a simple statistical analysis of the variability of the measurements are presented very briefly in the hope that time may be saved for other workers who contemplate such measurements. No discussion of the various methods for measuring growth rates has been undertaken, nor are the methods used in this study advocated; but because of simplicity, some procedure of this type is often adopted.

The plants measured were grown on 1/30-acre plats of the agronomy field in accordance with accepted cultural practices, and were probably representative of the variability that might be found elsewhere. No unusual precaution was taken to secure uniformity in plant size.

The measurements were made with a caliper improvised from a meter stick with a fixed arm making a right angle at the tip of the stick, and a movable arm, also vertical to the stick, held by a brass clamp. Stations were chosen at spaced intervals, and the spacing was changed for each measuring date. Height measurements for cabbage and tomatoes were taken from the ground line to the highest part of the plant directly above the point where the stem emerged from the soil, and at the portions of the row nearest the predetermined stations for celery, beets, and spinach. Width was measured across the row, and at the place where the height measurements were made.

The probable errors (Table 1) are presented as the percentages of the means to simplify the comparisons. The measurements of cabbage and celery improved in uniformity as the crops grew in size, and this was true in lesser degree for beets. The products of height multiplied by width were less uniform than either dimension alone, showing a tendency for tall plants also to be wide, rather than narrow. The two dimensions were not compensatory.

Measurements were the most uniform for tomato vines and least uniform for celery. If a 10% difference between measurements is considered significant, probable errors of 3% should be allowable. Grouping the crops measured in three categories, this average accuracy for the season could have been approximated by 10 measurements of height or width for spinach and tomatoes, 15 measurements for beets and cabbage, and 20 measurements for celery.

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[3] SMITH, JOHN B., CRANDALL, FRED K., and FREAR, DONALD E. The relative effect of single and fractional applications of soluble nitrogen on nitrates in soil and plant and on the yields of certain vegetable crops. Jour. Amer. Soc. Agron., 24:203–221. 1932.

TABLE 1.—*The variation in measurements of height, width, and the product of height x width for market garden plants, expressed as the percentages that the probable errors of the means are of the means.*

Crop	Number of plats averaged	Plants measured each plat	Dimension		$\frac{P_E M \times 100}{M}$							
			At start	At finish								
Cabbage	2	30			May 21	June 3	June 13	June 18	June 26	July 2	July 9	Average
Height, cm			10	30	2.49	2.23	1.70	1.71	1.52	1.49	1.74	1.84
Width, cm			13	59	3.19	3.16	2.33	1.97	1.53	1.63	1.35	2.17
Product, cm²			134	1774	4.90	4.65	3.54	3.20	2.64	2.60	2.16	3.38
Tomatoes	3	25			June 18	June 26	July 2	July 9	July 16	July 24	July 30	
Height, cm			31	48	1.73	1.62	1.55	1.28	1.44	1.67	1.94	1.60
Width, cm			29	91	1.74	1.83	1.92	1.73	2.04	2.08	1.99	1.90
Product, cm²			905	4193	4.71	2.57	2.58	2.40	2.56	2.88	2.69	2.91
Celery	3	50			Aug. 7	Aug. 20	Aug. 27	Sept. 4	Sept. 11	Sept. 19	Sept. 27	
Height, cm			11	40	2.04	1.97	2.65	2.56	1.35	1.23	1.07	1.84
Width, cm			13	58	2.32	2.09	2.09	1.91	1.38	1.26	1.10	1.74
Product, cm²			140	2358	3.57	3.77	4.20	4.06	2.46	2.19	1.90	3.16
Beets	2	50			Sept. 11	Sept. 19	Sept. 26	Oct. 5	Oct. 14			
Height, cm			21	32	1.71	1.32	1.11	1.14	1.76	—	—	1.41
Width, cm			23	36	2.12	1.44	1.41	1.28	1.53	—	—	1.56
Product, cm²			493	1181	3.18	2.16	2.01	2.07	2.57	—	—	2.40
Spinach	2	50			Sept. 19	Oct. 5	Oct. 14					
Height, cm			14	16	1.36	1.48	1.60	—	—	—	—	1.48
Width, cm			18	27	1.32	1.21	1.24	—	—	—	—	1.26
Product, cm²			250	392	2.47	2.32	2.40	—	—	—	—	2.40

RELATION BETWEEN FALLOWING AND THE DAMPING-OFF OF ALFALFA SEEDLINGS[1]

C. O. Grandfield, C. L. Lefebvre, and W. H. Metzger[2]

An experiment was conducted from 1930 to 1935 at the Kansas Agricultural Experiment Station in cooperation with the Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, to determine the length of fallow period necessary to restore the subsoil moisture removed by a preceding alfalfa crop. Alfalfa was seeded each fall, beginning with the fall of 1930, on two series of plats one of which had been fallowed and the other cropped with a rotation of sorghum, corn, wheat, oats, and alfalfa. Thus, the fallow period was lengthened each year until, in 1934, the alfalfa was sown on soil that had been fallowed 5 years and also on soil that had been continuously cropped. As the period of fallow increased to 3 years, a decrease in the vigor of alfalfa seedlings became apparent; this reduction in vigor becoming even more pronounced following 4 and 5 year periods of fallowing.

The first symptoms of the diseased condition were a retardation of growth, lack of vigor, and finally a yellowing of the entire plant. Fig. 1 shows the stand resulting from the seeding made in the fall of 1934 after 5 years of fallow. Many of the primary roots soon after emergence of the young seedlings were found to be decayed below the surface of the soil. Localized lesions frequently developed on the hypocotyls of the seedlings prior to their emergence. If the plants survived, it was because lateral roots had developed above the decayed portion. The retardation of growth or the dying of the plants seemed to be the result of the loss of a part or all of the root system. Those plants which survived gradually developed a root system capable of sustaining normal plant growth and the earlier injurious effect of the disease was not evident after the first cutting the following spring.

The appearance of the diseased seedlings is shown in Fig. 2. The seedlings at the left labeled No. 1 show the presence of small, brown cankers on the roots which are characteristic symptoms of an early stage of the disease. In No. 2 the canker is girdling the root, while in No. 3 the roots have rotted off completely and brown spots have developed on the hypocotyls. In No. 4, the lower part of the root has decayed and sloughed off and lateral roots have formed just above the injured portion. From field counts made in measured areas of the 1933 seeding after 4 years of fallowing, 55% of the plants were diseased. From measured areas of the 1934 seeding after 5 years

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[1] Cooperative Investigation of the Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, and the Kansas Agricultural Experiment Station, Manhattan, Kan. Contribution No. 248, Department of Agronomy and No. 351, Department of Botany. Received for publication July 18, 1935.

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of fallowing, 33% of the stand obtained remained the next spring, while 70% of the plants on the cropped plats survived.

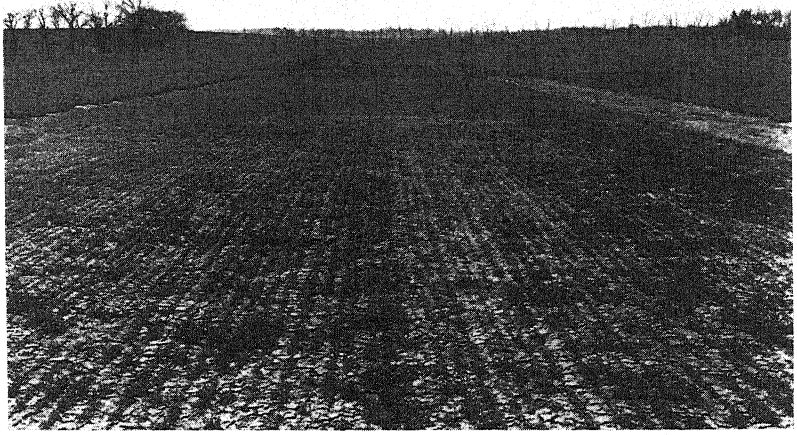

FIG. 1.—Alfalfa seeded in the fall of 1934, after 5 years of fallow (foreground) and after 5 years cropping system (background).

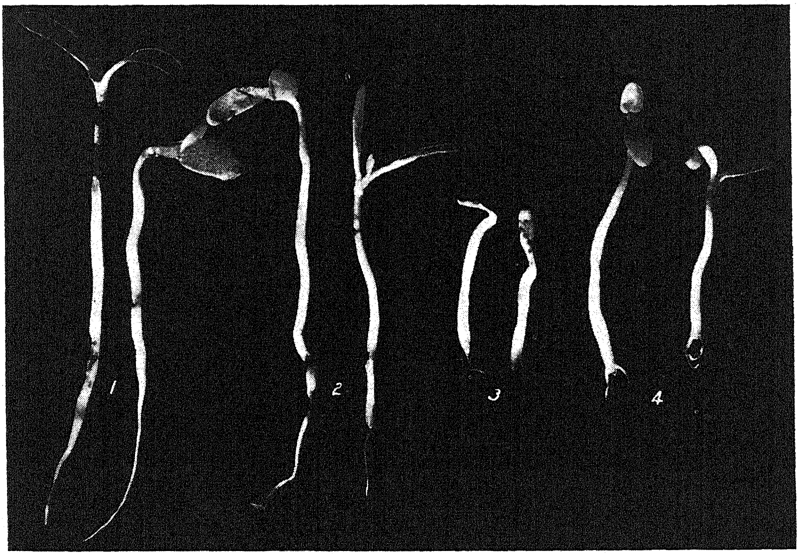

FIG. 2.—Diseased alfalfa seedlings from soil fallowed 5 years.

In order to determine the effect of the disease on the development of the root system of older seedlings (80 days), a block of soil 1 foot wide, 4 feet long, and 2 feet deep was removed from a cropped and also from a fallowed plat. The soil was carefully washed from the alfalfa roots, which were then measured as to diameter and length. The data in Table 1 show that the cropped soil contained a greater number of large and long-rooted plants in a measured area than the fallowed soil. It was also evident from observation that there were many more lateral and fibrous roots on the plants from the cropped soil.

TABLE 1.—*Alfalfa roots classified according to diameter 1 inch below the crown and according to length from a 4 square foot area in both fallowed and cropped plats.*

Plat treatment	Number of plants with a root diameter of							Total number plants
	0–½ mm	½–1 mm	1–1½ mm	1½–2 mm	2–2½ mm	2½–3 mm	3 mm	
Fallow....	0	17	60	50	26	—	—	153
Cropped..	0	11	29	32	64	15	5	156
	No. of plants with roots of the length indicated							
	0–15 cm	15–25 cm	25–45 cm	45–60 cm				
Fallow....	69	38	15	31				153
Cropped..	11	39	32	74				156

PRELIMINARY TRIALS

In an attempt to determine the cause of the diseased condition of the seedlings, soil was brought into the greenhouse from both the fallowed and cropped plats, subjected to various treatments as shown in Table 2, and then seeded to alfalfa. The results obtained from an examination of more than 20,000 seedlings in these experiments indicate that the diseased condition was caused by some pathogenic organism, since any form of partial or complete soil sterilization seemed to decrease the number of diseased plants. Three forms of sterilization were used. In the first, soil was steamed in an autoclave

TABLE 2.—*Greenhouse and field counts showing the effect of different soil treatments on the occurrence of diseased alfalfa seedlings.*

Treatment	Number of tests	Average number seeds planted	Average number plants	Percentage of diseased plants
		Fallowed Soil		
No treatment............	4	266	141	72
Dry heat sterilization.....	4	235	183	6
Steam sterilization........	2	237	177	7
Formalin................	1	240	178	20
CaO...................	2	231	160	39
Aerated.................	1	273	167	65
Wheat straw (chopped)...	2	203	90	74
		Cropped Soil		
No treatment............	3	231	172	13
Aerated.................	1	217	152	18

at 15 pounds pressure for 3 hours; in the second it was treated with dry heat in an oven at 100°C for 24 hours; and in the third the soil was sprayed with formalin, mixed, and covered for 48 hours. The steam and dry heat sterilizations of the fallowed soil reduced the number of diseased seedlings to 7 and 6%, respectively, while the formalin treatment reduced the number to 20%.

Fallowing had a tendency to deflocculate the soil which became tight and compact slightly below the surface with the result that aeration of much of the subsurface soil was somewhat inhibited. Additional experiments were conducted to learn what effect certain chemical and physical characteristics of the soil might have upon the inception of the disease. Organic matter in the form of chopped wheat straw was added to certain lots of soil taken from fallowed plats in order to improve its physical condition and another portion of the fallowed soil was placed in a thin layer before an electric fan and stirred frequently for 48 hours in order to aerate it thoroughly. The seedling counts from these treatments are nearly the same as the untreated fallow soil. In one instance not recorded in the table, pure sand was added to change the physical condition of the soil, but there was no decrease in the number of diseased seedlings.

Calcium oxide at the rate of 10,000 pounds per 2,000,000 pounds of soil was added to one lot of soil. At this rate there seemed to be some sterilizing effect and a decrease in the number of diseased plants resulted.

ISOLATION OF THE ORGANISM

As the results of the preliminary trials indicated that the diseased condition of the seedlings was not due to adverse physical or chemical factors, an effort was made to isolate some organism suspected of parasitizing the plants. A number of diseased plants was collected from the field, their roots washed in sterile distilled water, dried between sheets of sterile filter paper, and placed on corn meal agar, while others were left in distilled water several days before being placed on agar. After a day or two, hyphae emerged from the roots, and by cutting the tips of the radiating strands of mycelium with a sterile scalpel, pure cultures of various fungi were obtained. These belonged for the most part to the Fusarium, Helminthosporium, Trichoderma, and Pythium groups, with the last strongly predominating. These various fungi were then grown on a mixture of sterile oats and barley and different amounts were used to inoculate sterile soil that was later planted to alfalfa. Of the several fungi tested only members of the genus Pythium were pathogenic to the alfalfa seedlings.

In order to make an additional test of the pathogenicity of the Pythiums, one of the isolates was tested by thoroughly mixing various amounts of inoculum with soil adjusted to a definite acidity. It was reported by Buckholtz[3] in 1934, that a damping-off of alfalfa seedlings caused by a species of Pythium was especially severe in acid soils. It appeared desirable, therefore, to determine the relation-

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[3] BUCKHOLTZ, W. F. The rôle of damping-off disease in relation to failure of alfalfa stands on some acid soils. Science, 80:503. 1934.

ship of soil reaction to the activity of the organism isolated from Kansas soils. Flats were filled with 25 pounds of sterilized soil in which the reaction had been adjusted by addition of appropriate amounts of sulfuric acid or calcium hydroxide, and various amounts of inoculum were mixed with the top ¾ inch of the soil. The results of this test are summarized in Table 3.

TABLE 3.—*Effect of different amounts of inoculum and soil acidity on the emergence of alfalfa seedlings.*

Approximate pH value of the soil	Percentage of plants emerging when the following amounts of inoculum were used per 25 pounds of soil					Controls %
	113 grams	56 grams	30 grams	15 grams	7 grams	
3	—	—	—	1	1	2
4	0	14	19	34	64	82
5	1	5	15	23	48	84
6	1	2	10	18	44	84
7	2	2	4	12	41	89
8	2	1	3	20	38	86
9	—	—	—	23	38	83

It is evident from these data that, as would be expected, a soil with a pH as low as 3 is too acid for alfalfa plants since even the control had a very poor stand. It was also apparent that, as the amount of inoculum was reduced, the percentage of plants emerging increased. In this test, 56 grams of sterile oat-barley mixture was used in the control because it had been found in previous experiments that the amount of sterile oat-barley used had little or no effect on the stand of alfalfa. A similar test was made using only 7 and 15 grams of inoculum at various degrees of soil acidity. In this test the seedlings were carefully removed from the soil about 7 days after emergence and the number of diseased plants recorded. A summary of the results is presented in Table 4. It is again apparent that the presence of a larger amount of inoculum in the soil increased the severity of the disease. The data in Table 4, represented graphically in Fig. 3, indicate that the disease was most severe in soils ranging in reaction from pH 6 to pH 8, inclusive, and that when the pH was below 6 the percentage of diseased plants decreased materially.

TABLE 4.—*Effect of concentration of inoculum and degree of soil acidity on the damping-off of alfalfa seedlings caused by a species of Pythium.*

pH value	Percentage germination controls	Percentage diseased plants		
		Controls	7-gram inoculum per 25 lbs. of soil	15-gram inoculum per 25 lbs. of soil
4.05	87	17	33	43
5.08	90	4	26	44
6.01	89	13	67	91
6.94	91	5	49	88
7.70	86	9	65	74
8.21	84	15	59	58

Tests with inoculated soil in tanks in which the soil temperature was held at varying levels from 15° to 37°C indicated that the fungus was much more virulent at the lower temperatures. At the higher temperatures many infected plants survived. These results seem to be in agreement with those found under field conditions during the exceptionally hot summer of 1934. The high soil temperatures seemed to have a partial sterilizing effect as seed planted on fallowed soil that year (1934) produced better stands than those from plantings made on similar soil the previous fall when the temperatures were more moderate.

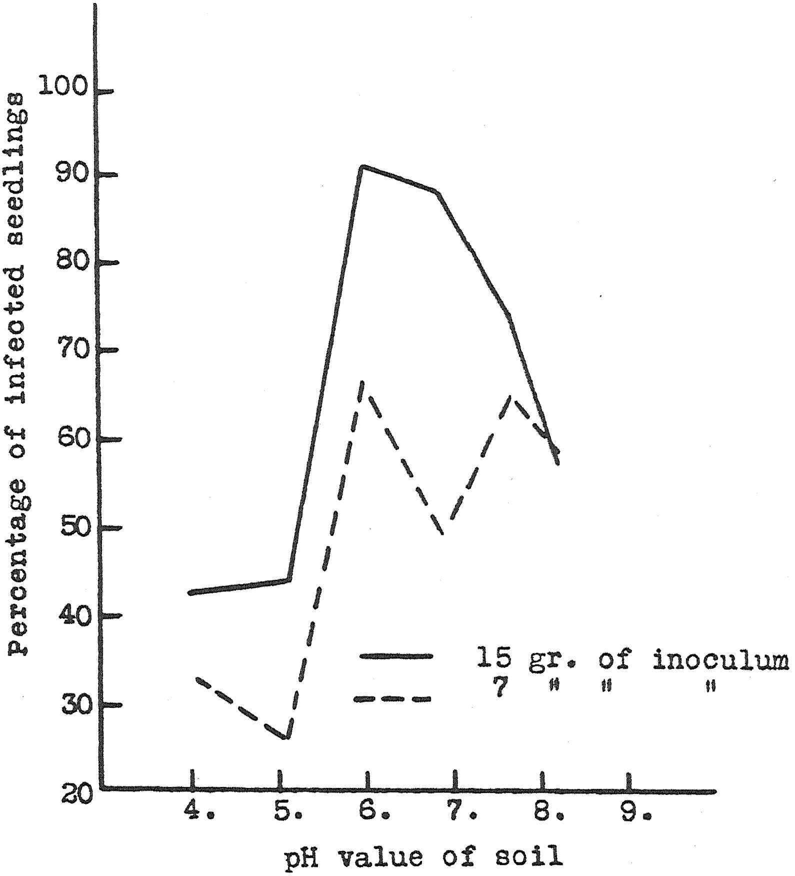

FIG. 3.—Relationship of the pH value of the soil to the percentage of alfalfa seedlings infected by a species of Pythium.

Attempts at developing methods of controlling the disease or increasing the percentage of seed germination on fallowed soil in the field have not been made, but investigations on this phase are now being conducted. Also the effect of the fungus on seedlings of various legumes and other crop plants is being studied.

DISCUSSION

Fallowing soil before seeding alfalfa is commonly practiced for the purpose of storing moisture and possibly as a result of this moisture storage more favorable conditions were brought about in the soil for the development of *Pythium* spp. From the results presented it may be concluded that the disease was caused by a fungus which in this experiment became more prevalent as the length of the fallow period increased. The length of fallow period necessary to cause a sufficient accumulation of the fungus to be harmful to alfalfa seedlings was not determined, but it is known that after 2 years of fallow the stand was materially reduced in some instances and also that 1 year of fallow has caused a weakening of the plants to a noticeable degree.

The data presented from the greenhouse tests show that as the amount of inoculum was increased the number of seedlings emerging from the soil was greatly decreased, indicating that where the organism is concentrated in the soil seedlings are killed soon after germination and also that the percentage of diseased plants increases as the pH value approaches the neutral point, reaching a maximum between pH values of 6 to 8. The differences recorded in the germination under the different pH values are small and probably are not significant. The soil on which the fallow experiment was conducted had a pH of 5.50 and grows alfalfa well without liming. After 5 years of fallowing the pH value was 5.21 which alone did not affect the growth of alfalfa.

SUMMARY

During the years 1930 to 1935, inclusive, alfalfa seed planted on soil fallowed for periods varying from 1 to 5 years have produced seedlings with less vigor and eventually poorer stands than seedlings grown on soil previously cropped. While the results of this experiment indicated that reduced stands would not result until after 3 years of fallow, observations in other sections of Kansas suggest that the difficulty might result from only 1 to 2 years of fallow.

Reduced stands proved to be due to the death of seedlings resulting from infection by fungi belonging to the genus Pythium. The organism was most pathogenic in soils in which the pH varied from 6 to 8.

A TABLE FOR TRANSFORMING THE CORRELATION COEFFICIENT, r, TO z FOR CORRELATION ANALYSIS[1]

H. H. Love[2]

THE purpose of this paper is to set forth a table for transforming the correlation coefficient, r, to z, for use in correlation analysis, in accordance with the methods presented by Fisher.[3] At the same time some examples are given to demonstrate the method of using the table.

In connection with correlation studies it is often important to compare correlation coefficients. That is, there may be two correlation values obtained for the same characters under different conditions, or correlation coefficients obtained for various characters, and in either case a comparison of these correlation coefficients may be valuable. The usual method of making such comparisons is to determine the probable errors or the standard errors of the correlation coefficients and then obtain the difference between the correlation coefficients and the error of this difference, which is the square root of the sum of the squares of the two errors. The difference between the correlation coefficients is then interpreted on the basis of the value of the error of the difference. Unless the difference is three or more times the probable error or two or more times the standard error, it is not considered significant. In some investigations it is also desired to combine correlations that have been determined from several populations of similar material, either by averaging the correlation coefficients or obtaining the weighted average.

It is recognized that correlation coefficients obtained from a small number of observations are not so reliable as when based on a larger number and at the same time, as pointed out by Fisher, the correlation coefficient, r, obtained from a small number of individuals is not distributed normally. For this reason it is better to use some means of comparing correlations based on a constant which is a function of the correlation coefficient but which by nature is more nearly normally distributed. Fisher suggests such a constant, z, which is obtained from

$$z = \tfrac{1}{2}\{\log_e (1 + r) - \log_e (1 - r)\}$$

or

$$z = r + 1/3r^3 + 1/5r^5 + 1/7r^7 + 1/9r^9 \ldots\ldots$$

The value of z may be calculated from either of the above equations. If tables of the natural logarithms are available it is a simple matter to substitute the values for $\log_e (1 + r)$ and $\log_e (1 - r)$ and obtain the value of z. If tables of natural logarithms are not available the common logarithms may be used and the values of

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[1] Paper Number 213, Department of Plant Breeding, Cornell University, Ithaca, N. Y. Received for publication August 3, 1935.

[2] Professor of Plant Breeding.

[3] FISHER, R. A. Statistical Methods for Research Workers. London: Oliver & Boyd. Ed. 5. 1934.

the common logarithms multiplied by the factor 2.302585093 to convert them to natural logarithms. For example, if an r value of .50 has been obtained, the z value is determined from tables of common logarithms as follows:

$\log (1 + r) = \log 1.50 = .1760913$ and $.1760913 \times 2.302585093 = .405465$

$\log (1 - r) = \log .50 = 9.6989700 - 10$ and $9.6989700 - 10 \times 2.302585093 = 9.306853 - 10$ and $\frac{1}{2}\{\log_e (1 + r) - \log_e (1 - r)\} = \frac{1}{2}\{.405465 - (9.306853 - 10)\} = .5493$

This gives a z value to four decimal places of .5493. With the second equation, where

$$z = r + 1/3r^3 + 1/5r^5 + 1/7r^7 + 1/9r^9 \ldots\ldots$$

substituting the value of r, .50, and obtaining the values for the first five terms, z is found to be .54925.

When tables of natural logarithms are not available these methods of determining z are laborious and it is desirable to have a table which will make it possible to change from r to z or from z to r directly. Fisher has published such a table, in which corresponding values of r for certain values of z are given. It is often more convenient to obtain the z value directly from the value of r, and for this reason the table presented here as Table 1 has been prepared by Miss Frances Feehan of the Department of Plant Breeding at Cornell University.

This table gives the values of z to four decimals for values of r from .01 to .90 read to two decimals. For the higher values of r three decimals have been retained, proceeding by steps of .005. For all ordinary comparisons it is sufficient for practical purposes to obtain z from r by interpolating from the values given in this table. For example, for an r value of .337 it is found by interpolating from Table 1 that the corresponding z value is .3507. If z had been obtained exactly by taking the common logarithms and converting them to the natural logarithms and substituting in the first equation above, the same value for z, .3507, would be obtained. Taking another value for r, .712, and interpolating from the table, the z value is found to be .8913. If this z value had been obtained by the use of logarithms as above the result would have been .8912, a difference of .0001. For very high values of r the differences between the z values obtained by direct interpolation from the table and those determined according to the method above will be greater, but for most cases interpolation from the table will be sufficiently accurate. Where greater accuracy is desired, the value of z should be determined from r by means of logarithms, following the method illustrated above, or by reference to Fisher's table.

As stated above, the principal reason for transforming r to z is that z is more nearly normally distributed than is r, especially for small samples, and even with large samples r is not distributed normally for high correlations. Therefore, more exact comparisons may be made by using the z values rather than the r values. The methods of comparison are similar, that is, the significance of the difference between either the r or z values is based on the standard error of the difference. In order to complete the comparison by means of the z values it is therefore necessary to determine the standard error of the z values. The formula used for the standard deviation of r is

$$\sigma^r = \frac{1 - r^2}{\sqrt{N' - 1}}$$

This value is in error due to the fact that the true value of r cannot be known, and especially does this hold for small samples. The standard deviation of z is approximated very closely from

$$\sigma_z = \frac{1}{\sqrt{N' - 3}}$$

The formula for σ_2 is simpler in form and it is evident that it is independent of the correlation coefficient. A more convenient application is to deal with the variance, or

$$\sigma^2_z = \frac{1}{N' - 3}$$

TABLE 1.—*Table of z values, for values of r from .01 to .995.*

r	z	r	z	r	z	r	z
.01	.0100	.31	.3205	.61	.7089	.905	1.4992
.02	.0200	.32	.3316	.62	.7250	.910	1.5275
.03	.0300	.33	.3428	.63	.7414	.915	1.5574
.04	.0400	.34	.3541	.64	.7582	.920	1.5890
.05	.0500	.35	.3654	.65	.7753	.925	1.6226
.06	.0601	.36	.3769	.66	.7928	.930	1.6584
.07	.0701	.37	.3884	.67	.8107	.935	1.6967
.08	.0802	.38	.4001	.68	.8291	.940	1.7380
.09	.0902	.39	.4118	.69	.8480	.945	1.7828
.10	.1003	.40	.4236	.70	.8673	.950	1.8318
.11	.1104	.41	.4356	.71	.8872	.955	1.8857
.12	.1206	.42	.4477	.72	.9076	.960	1.9459
.13	.1307	.43	.4599	.73	.9287	.965	2.0139
.14	.1409	.44	.4722	.74	.9505	.970	2.0923
.15	.1511	.45	.4847	.75	.9730	.975	2.1847
.16	.1614	.46	.4973	.76	.9962	.980	2.2976
.17	.1717	.47	.5101	.77	1.0203	.985	2.4427
.18	.1820	.48	.5230	.78	1.0454	.990	2.6467
.19	.1923	.49	.5361	.79	1.0714	.995	2.9945
.20	.2027	.50	.5493	.80	1.0986		
.21	.2132	.51	.5627	.81	1.1270		
.22	.2237	.52	.5763	.82	1.1568		
.23	.2342	.53	.5901	.83	1.1881		
.24	.2448	.54	.6042	.84	1.2212		
.25	.2554	.55	.6184	.85	1.2562		
.26	.2661	.56	.6328	.86	1.2933		
.27	.2769	.57	.6475	.87	1.3331		
.28	.2877	.58	.6625	.88	1.3758		
.29	.2986	.59	.6777	.89	1.4219		
.30	.3095	.60	.6931	.90	1.4722		

The variance of z is equal to the reciprocal of $N' - 3$ and the standard error is the square root of this variance.

To show the application of Table 1 in the comparison of two correlation coefficients, the correlations between total yield of plant and average number of kernels per culm in oats for two different years are used. The correlation coefficients are .769 and .680, and the problem is to determine whether there is a real difference in the correlation of these two characters for the different years, or, in other words, whether environment has influenced the correlation. The steps in the method of comparison are given in Table 2.

The z values corresponding to the values of r are obtained from Table 1 by direct interpolation. For $r = .769$ the z value is 1.0179 and for $r = .680$ the z value is .8291, and the difference is .1888. There were 500 individuals in the population in the first year and 400 individuals in the second year, so the $N' - 3$ values for determining the standard errors are 497 and 397, respectively. The reciprocals of these $N' - 3$ values are obtained, giving the square of the standard error, or variance, of each z value. Since in this comparison the standard error of the difference is desired, these reciprocals are summed, giving the sum of the squares of the errors of the z values, and the square root of this sum, or .0673, is the standard error of the difference. The difference between the z values is, therefore, .1888 ± .0673. To be significant this difference must be two or more times its standard error, and on this basis there is a real difference between the correlation values used in this comparison. The conclusion is that environment has affected the correlation between these characters.

Another comparison is given in the second part of Table 2. In this case the characters number of culms per plant and height of plant in oats have been correlated with total yield of plant. The resulting correlation coefficients are compared to determine which character seems to have the greater effect on yield for this particular lot of data. The difference between the z values is .4101 ± .0634, which is highly significant and indicates that for these data number of culms per plant has a greater effect on total yield than does the height of plant.

TABLE 2.—*Method of comparing two correlation coefficients.*

	r	z	N'-3	Reciprocal N'-3
Correlations between total yield of plant in grams and average number of kernels per culm in oats for two different years				
First year	.769	1.0179	497	.00201207
Second year	.680	.8291	397	.00251889
	Difference = .1888±.0673			Sum = .00453096
Correlations between total yield of plant and number of culms per plant and between total yield of plant and height of plant in oats.				
Number of culms	.850	1.2562	497	.00201207
Height of plant	.689	.8461	497	.00201207
	Difference = .4101±.0634			Sum = .00402414

As already stated, this means of comparing correlation coefficients is more accurate than by using r directly, and the use of the z values is also more accurate for combining the results from several correlations. The purpose in combining correlation coefficients is to obtain a general value, or a weighted value, based on the correlations obtained from several independent studies of the same characters. For example, the same two characters may have been correlated for different years or under different conditions, and it is desired to combine these correlations, giving one general figure or constant weighted in accordance with the results obtained from the individual comparisons. The method of combining correlation coefficients by means of the z values is illustrated in Table 3.

TABLE 3.—*Combination of correlations.*

	r	z	N'-3	$(N'$-3$)$ z
Correlations between total yield of plant in grams and average number of kernels per culm in oats for two different years				
First year.........	.769	1.0179	497	505.8963
Second year.......	.680	.8291	397	329.1527
Weighted values...	.732	.9341 ±.0334	Sum = 894	Sum = 835.0490
Correlations between average weight of kernels per plant and average yield of culm per plant in oats for four different years				
First year.........	.464	.5024	822	412.9728
Second year.......	.337	.3507	497	174.2979
Third year........	.225	.2289	397	90.8733
Fourth year.......	.429	.4587	397	182.1039
Weighted values...	.386	.4071 ±.0218	Sum = 2113	Sum = 860.2479

Using the same correlation coefficients as in the first example in Table 2, the z values and $N' - 3$ values are obtained as before. Each z value is multiplied by the corresponding value of $N' - 3$, which gives a value weighted in accordance with the number in the population. These weighted values are summed and a weighted z value, .9341, is obtained by dividing this sum by the sum of the $N' - 3$ values. By direct interpolation from Table 1 the corresponding value of r for this weighted z value is found to be .732.

To determine whether this z value of .9341 is significant, in other words whether there is real correlation, the standard error is determined from the square root of the variance. This is the square root of the reciprocal of the sum of the $N' - 3$ values, which in this case is $\sqrt{\frac{1}{894}}$. This gives a standard error of .0334 for $z = .9341$, which indicates that z is highly significant and there is a fairly high correlation between the two characters.

It is possible to combine several correlation coefficients in this manner, continuing the steps as in the second example in Table 3. The data used here are the results obtained from correlating the average weight of kernels per plant and the average yield of culm per plant in oats for four different years. The individual correlation coefficients vary considerably, and by combining them on the basis of the z values a general value, .4071 ± .0218, is obtained, from which r is found to be .386.

These examples illustrate the application and usefulness of the table giving corresponding r and z values. As stated above, this table making it possible to read z directly from r is presented for the convenience of investigators. For nearly all practical applications sufficient accuracy is obtained by direct interpolation from the values in the table. However, where greater accuracy is desired the exact value of z to several decimal places may be obtained by the methods explained above.

BAGASSE AND PAPER MULCHES[1]

O. C. MAGISTAD, C. A. FARDEN, AND W. A. BALDWIN[2]

STRAW and paper mulches have been widely used in the commercial production of fruits and vegetables. The use of sugar cane bagasse as a mulch was used in Hawaii about 1930 by the Haleakala Pineapple Company which later became the Maui Pineapple Company. The beneficial effects obtained with pineapples led to a large scale experiment in which bagasse mulch was compared with paper mulch and with no mulch. In this experiment records of soil moisture, soil temperature, available soil nitrogen, and fruit yields were obtained. These data are presented in this paper.

REVIEW OF LITERATURE

Much of the literature on the use of paper mulches was reviewed by Hutchins (5)[3] in 1933, and only additional references will be included here. Mulches of this type definitely reduce weed growth and in this manner reduce cultivation and hoeing costs. In addition, mulches in general improve the growth of economic plants (6). One reason for better plant growth is that the soil temperatures are higher with reduced fluctuations under mulches, especially paper (8). Furthermore, reduction in weed growth is coupled with the effect of the mulch in reducing evaporation, resulting thereby in a conservation of soil moisture. Because of higher soil temperatures and greater soil moisture, biological processes in the soil are considerably accelerated. This results in a greater liberation of plant food, especially nitrates.

There appear to be no references on the use of sugar cane bagasse as a mulch, but this material should act as do straw mulches. If the mulch is incorporated with the soil, or if soluble material having a high carbon-nitrogen ratio is leached into the soil, a reduction in available nitrogen in the soil occurs. Under such conditions nitrates do not accumulate in the soil until the carbon-nitrogen ratio has been lowered (1, 9, 4).

EXPERIMENTAL PROCEDURE

The plan of the experiment consisted of 11 treatments involving the use of bagasse and paper as mulches. Two levels of nitrogen fertilization and two levels of bagasse representing light and heavy applications constituted the variables. Treatments and replications are shown in Table 1.

It will be observed that treatments B_3, C_3, and D_3 are duplicates of B_2, C_2, and D_2, respectively. It was originally intended that treatments B_3, C_3, and D_3 would receive iron sulfate spray while treatments B_2, C_2, and D_2, otherwise similar, would receive water only. The iron sulfate spray treatments, however, were made uniformly on all plats. Consequently B_3 is a duplicate of B_2; C_3 of C_2; and D_3 of D_2. An earlier fertilizer experiment in this locality showed that the use of phosphorus and potash did not increase yields. Hence the addition of these nutrients were omitted in this experiment.

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[3] Figures in parenthesis refer to "Literature Cited," p. 825.

TABLE 1.—*Treatments and replications employed in the experiment.*

Treatment symbol	Number of replications	Treatment Lbs. N per acre	 Kind of mulch
A_1	4	300	None
A_2	4	600	None
B_1	6	300	Paper
B_2	6	600	Paper
B_3	6	600	Paper
C_1	6	300	8 tons bagasse
C_2	6	600	8 tons bagasse
C_3	6	600	8 tons bagasse
D_1	6	300	16 tons bagasse
D_2	6	600	16 tons bagasse
D_3	6	600	16 tons bagasse

The experiment was installed on November 13, 1931. However, owing to a shortage of material, application of bagasse was not completed until 6 weeks later. The treatments occupied 62 plats. Each plat consisted of two four-row beds 150 feet long and systematically arranged by blocks. At a later date, however, the number of plats was reduced by omitting some of the A plats from the experiment. Some plats of the A treatments were retained to serve as a measuring stick with which to compare results with paper and bagasse treatments. Later developments, however, indicated that pineapples grew very poorly on the A treatments, and hence these treatments were omitted from further consideration 1 year after installation. This action finally reduced the number of plats from 62 to 54. There were 19,100 plants per net acre, planted in the usual manner (7).

The fertilization schedule and dates of application for the plant and ratoon crops are shown in Table 2.

TABLE 2.—*Date and rate of applications of nitrogen to plant ratoon crops.*

Treatments	Nitrogen in pounds per acre Plant crop At planting	 March 11, 1932	 Dec. 10, 1932	 Ratoon crop Apr. 19, 1933	 March 20, 1933	 Febr. 21, 1934	 Total for cycle
A_1 B_1 C_1 D_1	100	100	100	80	80	160	620
A_2 B_2 B_3 C_2 C_3 D_2 D_3	200	200	200	80	80	160	920

The amounts of nitrogen added to ratoons were left at a low level in order not to mask earlier effects. The dates of these applications were later than the ordinary plantation practice, due to the fact that the extremely dry weather during the first ratoon year left much of the fertilizer undissolved at times when plants generally received fertilizers.

Treatment effects on soil temperature, soil moisture, nitrification, and fruit yield served as measures for judging the superiority of one treatment over another.

RESULTS

TEMPERATURE RECORDS

Soil temperature records were obtained by means of recording soil thermographs manufactured by Julien P. Friez & Sons. Three soil thermographs were used, one each under paper, bagasse, and no mulch. The thermometer tube of each recorder was placed horizontally with the soil surface at a depth such that there were 2 inches of soil above it. These were installed January 5, 1932, and records under paper and bagasse were obtained until December 22, 1934, except for intervals of a few days when the clocks stopped. The temperature recorder under bagasse treatment gave successively lower temperatures in April and May 1933 and was replaced by a new instrument on June 17. At the end of the test, as well as at the beginning, all recorders were checked for accuracy and were found to be reliable with the exception noted above.

Maximum and minimum air temperatures read weekly were obtained in a standard shelter during a part of 1933.

The soil temperature results are condensed in Table 3.

SOIL MOISTURE

It has been demonstrated many times that the use of paper mulch especially in dry regions, has caused increased plant growth and fruit weights of pineapples. This increase is attributed in a large measure to increased soil moisture due to the use of paper mulch.

In order to compare and measure the action of bagasse against paper mulch on this growth factor, composite moisture samples were taken at three depths from all plats, except the A_3, B_3, C_3, and D_3 plats, *viz.*, 0 to 6 inches, 6 to 12 inches, and 12 to 24 inches taken at approximately 2-month intervals. The first sampling was taken January 1, 1932, about 2 months after the installation of the experiment, and nine samplings were obtained thereafter.

By omitting the B_3, C_3, and D_3 plats, 44 plats in all were sampled each time, and gave a total of 132 soil samples for each sampling. After the fifth sampling, however, the number taken was cut to 108 due to the omission of all the A plats. Up to and including the last series of samples which was taken March 16, 1934, the total number taken was 1,200 and is too voluminous to record in this report. However, Fig. 1 presents the data in graphic form and represents the average soil moisture contents of the replicate plats on the dates sampled for each treatment at the three depths.

WILTING COEFFICIENTS

The percentage of moisture in the soil when quick-growing indicator plants wilted was determined by the method outlined by Briggs and Shantz (2), except that lead foil was used as a seal in place of paraffin. All joints and edges received paraffin in addition. The indicator plants were sunflowers and cowpeas, and these were each grown in triplicate gallon cans. A total of 38 individual determinations from six cans gave a mean wilting coefficient of 18.7 with a standard deviation of 1.1% of the mean value.

TABLE 3.—*A condensed table of soil and air temperatures with the soil temperatures taken at a depth of 2 to 3 inches and all values given in degrees F.*

Month	Soil				Paper				Bagasse			
	Mean Max.	Variance	Mean Min.	Variance	Mean max.	Variance	Mean min.	Variance	Mean max.	Variance	Mean min.	Variance
					1932							
Jan.	84.64	13.70	70.02	3.09	89.50	17.76	67.93	3.36	76.52	1.86	69.81	1.20
Feb.	78.08	25.23	67.02	4.14	82.05	45.05	65.72	4.76	73.66	5.37	67.95	1.62
Mar.	88.03	22.55	70.32	1.35	93.98	42.69	68.15	9.75	78.84	7.97	69.68	3.41
Apr.	91.56	11.83	74.35	2.80	93.95	27.58	70.77	2.82	80.50	4.50	70.40	9.03
May	95.08	8.64	77.90	4.08	94.70	14.77	73.24	2.75	83.05	4.09	71.90	1.75
June	97.30	9.70	80.30	2.20	93.92	9.64	74.56	2.53	85.20	4.25	73.75	1.48
July	99.43	7.58	81.82	2.61	93.55	7.08	75.91	2.84	87.26	3.26	75.39	1.07
Aug.	99.27	7.56	82.01	2.36	92.63	7.06	76.04	2.33	87.02	3.47	75.69	1.31
Sept.	96.38	6.84	80.01	3.33	89.07	6.50	74.36	2.25	84.53	3.46	74.35	1.44
Oct.	94.54	11.16	78.24	1.90	85.35	6.16	72.31	2.01	82.07	4.01	72.65	1.17
Nov.	87.08	19.20	73.82	11.96	79.07	8.53	69.78	4.48	75.45	9.42	68.65	6.31
Dec.	85.17	7.33	69.93	2.44	74.88	1.51	66.06	2.01	70.38	1.26	63.74	2.34
Annual	91.38		75.48		88.55		71.24		80.37		71.16	
					1933							
Jan.	Air temperatures based on weekly readings of maximum and minimum thermometers				73.32	1.67	64.41	1.04	Temperature data from Jan. to July omitted because of unreliability; new recorder installed June 17.			
Feb.					73.10	3.63	65.57	3.00				
Mar.					73.03	6.18	64.66	2.10				
Apr.	87.9		52.8		73.89	5.67	65.24	2.44	—	—	—	—
May	89.6		56.0		76.26	1.41	67.07	0.92	—	—	—	—
June	90.4		58.1		76.04	1.69	67.43	0.68	—	—	—	—
July	91.9		57.7		77.06	0.83	68.62	1.62	77.95	0.92	70.88	1.34
Aug.	93.3		57.5		76.82	1.86	67.65	0.97	77.55	1.64	70.29	0.67
Sept.	94.4		57.8		75.70	1.45	66.76	0.81	77.32	0.63	70.03	0.57
Oct.	92.9		56.5		73.44	1.19	66.19	1.16	74.96	0.93	68.79	0.64
Nov.	89.8		54.0		68.79	8.79	62.83	5.78	71.25	4.01	66.27	3.49
Dec.	87.5		50.9		67.30	0.71	61.74	2.43	69.71	0.67	65.50	1.52
Annual					73.73		65.68					

NITROGEN DETERMINATIONS

Composite samples for nitrate and ammonia determination were taken from all plats which received 300 pounds of nitrogen per acre. Nitrates were determined by the method of Harper (4) and ammonia by a direct distillation of an acid sodium chloride extract of soil. Ammonia and nitrate content of the soil at two depths, 0 to 6 inches and 6 to 12 inches, were determined. Results obtained are visualized in Fig. 2. Nitrate content is superimposed on ammonia content for the same treatment.

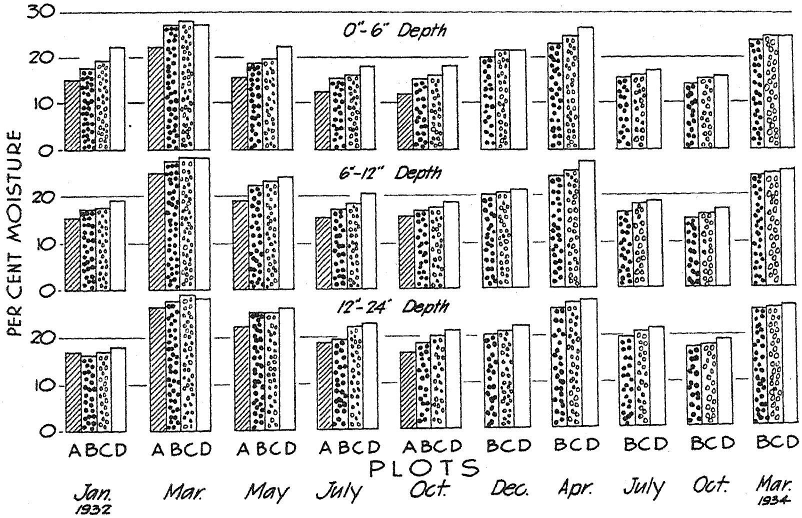

FIG. 1.—Soil moisture contents by treatments and dates for depths of 0 to 6 inches, 6 to 12 inches, and 12 to 24 inches. For explanation of letters A, B, C, and D, see Table 1.

PINEAPPLE YIELDS

Yields of pineapples were obtained by weighing all fruits as they ripened. The yield records were complicated by the fact that many plants did not fruit at the normal age, and also by the high incidence of fasciated fruits.

Table 4 shows the total number and weight of fruits collected from each treatment. The last column shows the average number of fasciated fruits found in the 1934 harvest. There were very few fasciated fruits in the summer of 1933 and no record of the number was kept, but in the summer of 1934 fasciation seemed more frequent than usual.

DISCUSSION

TEMPERATURE DATA

One of the outstanding results during 1932 was the small daily mean range of 9.21° F between the maximum and minimum temperatures under bagasse as opposed to a range of 17.21° under paper. Inspection of Table 3 shows that the mean minimum temperatures were approximately equal and that the increased range under paper resulted from higher maximum temperatures, especially during the early part of the year before the plants were large enough to shade the paper materially. On sunny days it became very warm under

TABLE 4.—*Fruit production to age of 30 months.*

Symbol	Treatment	Normal fruits			Fasciated fruits
		Number	Total weight, lbs.	Average fruit weight, lbs.	Average number per treatment
$A_{1, 2, 3}$	Soil alone	No crop	—	—	No crop
B_1	Paper+300 lbs. N	4,327	16,002	3.70	25
B_2	Paper+600 lbs. N	4,519	19,333	4.28	30
B_3	Paper+600 lbs. N	4,494	19,467	5.45	30
C_1	8 tons bagasse+300 lbs. N	4,462	18,188	4.07	34
C_2	8 tons bagasse+600 lbs. N	4,344	19,770	4.55	42
C_3	8 tons bagasse+600 lbs. N	4,430	20,095	4.54	38
D_1	16 tons bagasse+300 lbs. N	5,098	22,706	4.45	36
D_2	16 tons bagasse+600 lbs. N	4,292	21,009	4.89	42
D_3	16 tons bagasse+600 lbs. N	3,898	18,808	4.82	38
Difference necessary for significance, $P=0.05$				0.31	17

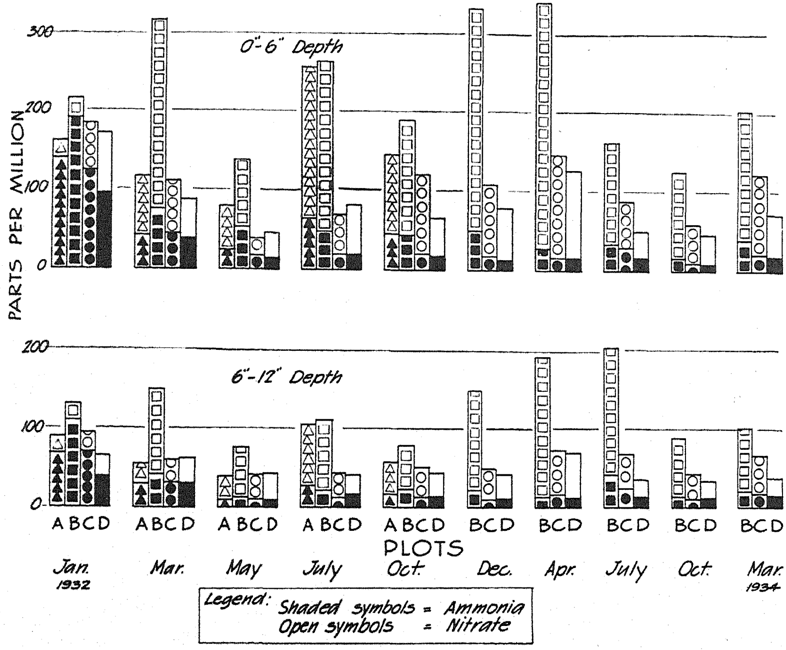

FIG. 2.—Ammonia and nitrate contents of soil under various mulches. The data are given for the 0 to 6 inch depth and 6 to 12 inches, and for various dates. All results are graphed as p. p. m. of nitrogen.

dark paper, and this led to greater variance between days for maximum temperatures under paper than under bagasse. In the latter part of the year with increased shading from plants the variance was diminished.

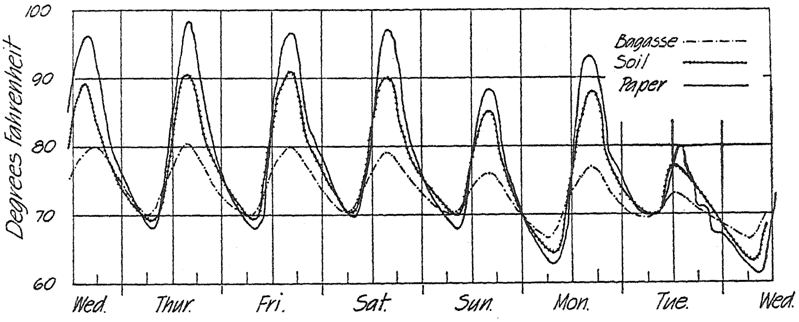

FIG. 3.—A typical week's record of soil temperatures at a depth of 2 inches under various mulches. The record presented is that for the week ending March 2, 1932.

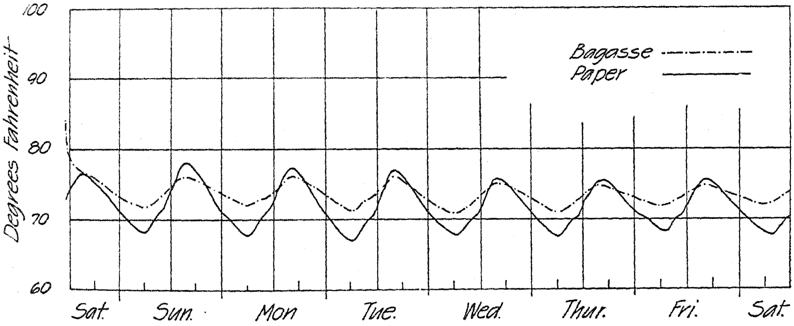

FIG. 4.—A typical week's record of soil temperatures at a later date, week ending June 24, 1933, when plants were bigger and shaded the soil.

The annual range between maximum and minimum temperatures was 15.90° on soil without mulch, which was less than that under paper. Here, too, the variance for maximum temperatures was great, as in the case of paper during the first of the year.

In order to illustrate the daily range in temperature under these soil covers, a week's record ending March 9, 1932, was selected as typical and appears in Fig. 3.

Fig. 4 shows the daily range in soil temperatures under paper and bagasse in the summer of 1933 at a time when the pineapples were large enough to shade the soil area completely.

MOISTURE RELATIONS

A glance at Fig. 1 will show that the moisture contents of the soil at several sampling dates were low in value. Indeed, the moisture contents of all samplings in the A plats, with the exception of the

March 1932 sampling, were so low that plant failure resulted. The soil moisture content at the time of sampling did not indicate for how long a period the moisture contents remained as determined in the sample. Rains and heavy dews might easily have occurred between the sampling periods and masked the true state of affairs. However, when a period of 2 years is considered, the condition of the plants at the end of that time would reflect the integrated effect of the moisture availability and this in turn would reflect the efficiency of the various mulches to conserve moisture at all times.

The low moisture contents obtained in the soil gave rise to the suspicion that these percentages were below the range of water availability and led to the determination of the wilting coefficient and the moisture equivalent. The method of Veihmeyer *et al.* (11) was used for moisture equivalent determination. The wilting coefficient was 18.7 and the moisture equivalent of the soil was found to be 27.9.

At certain times the actual moisture contents were lower than the wilting coefficient and the plants should have suffered from moisture starvation. Most of the plants, on the other hand, gave visual evidence of continued growth, and a check made by digging a trench around a few randomly selected plants, revealed that plant roots had penetrated beyond the sampling depth of 24 inches. The soil in the experimental area was porous and thus permitted plant roots to penetrate even to a depth of 4 feet.

This discovery tended to make useless the interpretation of the moisture results obtained in its relation to plant growth. The data collected, however, do not destroy their usefulness in determining the efficacy of the various mulches to conserve moisture in the soil.

Data from which Fig. 1 was prepared were subjected to statistical methods for ascertaining the effectiveness of various factors on moisture contents, such as effectiveness of (a) mulches, (b) amounts of nitrogen applied, (c) sampling depths, (d) sampling dates, and (e) interactions between these factors. The analysis of variance has been selected to evaluate the magnitude of these factors. The analysis assumes that all treatments have approximately the same standard deviation and that the values for each treatment are adequate samples of a homogeneous, normally distributed population. The analysis of variance is given in Table 5.

TABLE 5.—*Analysis of variance of soil moisture contents.*

Variance due to	Degrees of freedom	Sum of squares	Mean square	F values obtained	F values for significance	
					P=0.05	P=0.01
Total	209	3580.47	—	—	—	—
Mulches	3	391.71	130.57	159.2	2.66	3.90
Sampling dates	9	2805.44	311.72	380.2	1.94	2.51
Depths of sampling	2	203.33	101.67	124.0	3.05	4.73
Amounts of N fertilizer	1	0.06	0.06	13.7	254.32	6366.48
Interactions	17	34.40	2.02	2.5	1.71	2.13
Residual (error)	177	145.53	0.82	—	—	—

The last two columns indicate whether or not the effect of the several factors were significant. The method for testing significance was that of Snedecor (10), and the reader is referred to his article for details.

Reference to the last column indicates that differences in moisture contents between sampling dates, depths, and the kinds of mulches used were highly significant.

SAMPLING DATES

The significant differences in moisture contents between sampling dates were due to the rains that fell. Table 6 records the rainfall for the period of the experiment from November 1931 to October 1934.

TABLE 6.—*Rainfall in inches from Nov. 1931 to Dec. 1934.*

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Totals
1931...	—	—	—	—	—	—	—	—	—	—	0.43	1.95	2.38
1932...	1.39	10.40	0.00	0.26	0.00	0.00	0.00	0.00	0.64	0.00	0.00	0.65	13.34
1933...	0.34	3.80	2.17	1.13	0.00	0.00	0.00	0.00	0.00	0.00	1.03	6.77	15.24
1934...	0.62	1.08	0.30	1.10	10.7	0.20	0.42	0.41	0.10	0.00	0.00	0.00	5.30

It is readily seen that the rainfall in December 1931; January and February 1932; February, March, April, November, and December 1933; and February, April, and May 1934 are reflected in the high moisture contents of the soils sampled March 21, 1932; April 11, 1933; and March 16, 1934. Between May and December of the years 1932 and 1933 very little rain fell on the experimental area, and hence the moisture contents of the soils were low during these periods.

MULCHES

While the mean moisture contents of the soil under different mulches varied among themselves within a narrow range, the experimental error was sufficiently small to demonstrate the existence of real differences in moisture contents between them. The mean values are shown in Table 7 accompanied by their standard errors.

TABLE 7.—*Mean percentage of moisture in soil of each mulch treatment, means of all sampling dates, fertilizer levels, and depths.*

Moisture content	Treatments				General mean	Difference for significance	
	No mulch	Paper mulch	8 tons bagasse	16 tons bagasse		P=0.05	P=0.01
In per cent....	17.95	20.25	21.24	22.20	20.76	0.42	0.55
In per cent of general mean	86.6	97.6	102.2	107.0	100.0	2.0	2.6

Examination of the values in Table 7 shows that bagasse was distinctly better than paper for conserving moisture, and that paper in turn was distinctly better than plain soil mulch. Without a paper or bagasse mulch the plants failed to grow as shown in Fig. 5.

NITROGEN FERTILIZATION

As expected, the moisture content of the soil was not influenced by use of an increased amount of nitrogenous fertilizer. The mean moisture contents were 20.75 and 20.78%, respectively, for additions of 300 and 600 pounds of nitrogen per acre. The difference necessary for significance was 0.21%.

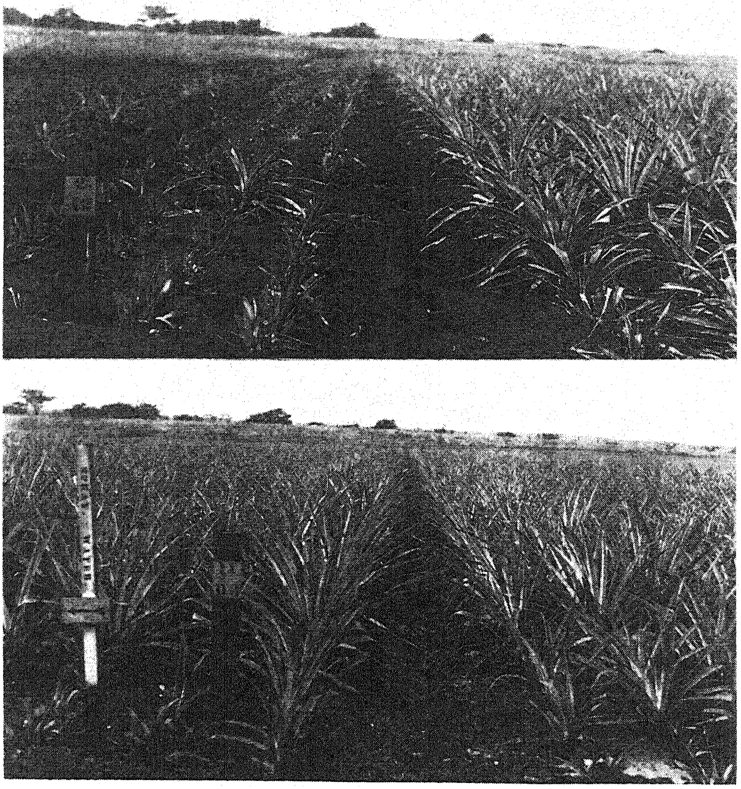

FIG. 5.—Effect of mulch on pineapples.

Above, soil mulch only on left, paper mulch on right. Below, 16 tons bagasse on left, paper mulch on right. Pictures taken Jan. 30. 1933. Pineapples 14 months old.

DEPTH OF SAMPLING

Differences in soil moisture contents at various depths were great, as indicated in Table 8.

This condition is not uncommon. The moisture in the upper layer of soil being closer to the soil surface is either taken up and transpired through plants, or exposed to evaporation through greater air circulation.

TABLE 8.—*Mean moisture content of soil at various depths, means of all sampling dates, fertilizer levels, and mulch treatments.*

Depth in inches	Mean moisture content, %
0–6	19.57
6–12	20.75
12–24	21.98
Necessary for significance	0.30

NITRATES

Reference to Fig. 2 shows the outstanding performance of the paper mulch treatment in maintaining a high nitrate content in the soil. The 8 tons and 16 tons of bagasse treatments appear to have a lower amount of nitrates than even the no-mulch treatment. This demonstrates the long-established finding that an excess of carbohydrate material in the soil brought about by the mixture of bagasse with the soil promotes the development of a high bacterial population which makes use of nearly all the nitrates available in the soil for its growth. Paper mulch by reason of its mode of preparation and its lack of intimate mixture with the soil is not so readily decomposable as is bagasse and hence does not cause the immediate existence of a high carbon-nitrogen ratio in the soil.

With a combined action of maintaining a temperature and retaining moisture content favorable to bacterial growth, the paper mulch serves as a better medium for the increased production of nitrates for plant use.

AMMONIA

The amount of ammonia produced at the beginning of the experiment was high under all mulches, but decreased progressively with time. Evidently the soil was well stocked with bacteria to change the ammonia formed by decomposition into nitrates.

The analysis of variance indicated significant differences in ammonia-nitrogen and nitrate-nitrogen between mulches, depth of sampling, and sampling dates. Through the use of the standard error of the treatments, the analysis showed that paper mulch was better than all other mulches for maintaining a high concentration of nitrates, and that there were no significant differences between nitrate contents due to no-mulch treatment and bagasse at either level. The no-mulch and paper treatments contained significantly larger amounts of ammonia than the bagasse treatments. The top layer of the soil, i. e., 0 to 6 inches, contained significantly greater quantities of ammonia and nitrates than the lower depths.

FRUIT YIELDS

Each plat of the experiment contained 900 plants which is a larger number of plants per plat than is usually necessary to demonstrate a 5% significance in fruit yield between any two treatments (7). Approximately 80% of the possible number of fruits matured and included an unusually large percentage of "hold-overs", fruits which ripen after the normal period.

The standard errors of each treatment for average fruit weight and number of fasciated fruit, respectively, were computed and are indicated in the last row of Table 4.

With the use of the average fruit weight as an index of the efficiency of mulches, Table 4 shows that nitrogen was a limiting factor and that the bagasse treatments produced heavier fruits than the paper treatments. This statement is more clearly borne out when we consider the results presented in Tables 9 and 10.

TABLE 9.—*Average fruit weight in pounds with varying nitrogen fertilization, means of all mulch treatments.*

Mean values	300 lbs. N	600 lbs. N	General mean	Stand. error of diff.	Diff. for sig.	
					P=0.05	P=0.01
In pounds.............	4.09	4.59	4.419	0.08	0.16	0.21
In per cent of general mean...............	92.5	103.8	100.0	1.74	3.35	4.79

TABLE 10.—*Average fruit weight in pounds for various mulch treatments, means for two nitrogen levels.*

Mean values	Paper	8 tons bagasse	16 tons bagasse	General mean	Stand. error of diff.	Diff. for sig.	
						P=0.05	P=0.01
In pounds....	4.10	4.41	4.75	4.419	0.09	0.18	0.24
In per cent of general mean	92.8	99.8	107.4	100.0	2.00	4.08	5.50

Odds exceeding 100 to 1 were obtained to indicate that fruit yields due to 600 pounds of nitrogen per acre were higher than those due to 300 pounds of nitrogen per acre; that 8 tons of bagasse and 16 tons of bagasse treatments produced significantly higher yields than paper mulch treatment; odds exceeding 100 to 1 were obtained to indicate that 16 tons bagasse treatment produced higher fruit yields than 8 tons bagasse treatment.

A note is inserted here to call attention to the fact that at the installation of the experiment bagasse was laid between the beds of the paper plats as well as between the beds of the bagasse plats. No doubt this bagasse covering has helped the paper-treated plats to make a good showing. Also, it was found by analysis that the amount of soluble iron in the leachate of bagasse was considerably more than amounts of iron occurring naturally in the soil solution. It is possible then that the plants in bagasse-treated plats may have obtained some additional iron and thereby permitted the plants to perform better in these plats than those grown in plats covered with other forms of mulches. However, more information was necessary to establish the probability that iron was a limiting factor.

SUMMARY

A six replication experiment of nine treatments was installed to compare bagasse as a mulch against paper mulch and no mulch for pineapples.

Data of 2 years' continuous records of soil temperatures under the mulches, of soil moistures, nitrates, and ammonia determined periodically, and of pineapple fruit yields obtained at harvest time were used to measure the efficiencies of the various mulches. The following conclusions have been reached:

1. The annual mean range between the maximum and minimum temperatures was one-half as great under bagasse as under paper; that for the no-mulch plats being less than that under paper.
2. Soil moistures were highest in bagasse-treated plats, followed by papered and no-mulch plats.
3. The first 6 inches of soil contained significantly less moisture but more nitrate than soil at greater depths.
4. Nitrate content of the soil was greater in paper treatment than in the bagasse treatment or soil alone.
5. Fruit yields were highest in bagasse-treated plats.
6. Lack of sufficient nitrogen was a limiting factor for maximum fruit production.

LITERATURE CITED

1. BEAUMONT, A. B., and CROOKS, G. CHAPMAN. The influence of a mulch on soil nitrates. Soil Science, 36 : 121–123. 1933.
2. BRIGGS, L. J., and SHANTZ, H. L. The wilting coefficient for different plants and its direct determination. U. S. D. A. Bur. Plant Ind. Bul. 230. 1912.
3. FULLER, JAMES E., and JONES, LINUS H. The influence of temperature on the nitrate content of soil in the presence of decomposing cellulose. Soil Science, 34 : 337–351. 1932.
4. HARPER, HORACE J. The accurate determination of nitrates in soil. Ind. and Eng. Chem., 16 : 180–183. 1924.
5. HUTCHINS, A. E. Mulch paper in vegetable production. Minn. Agr. Expt. Sta. Bul. 298. 1933.
6. LONGLEY, A. T. The first annual short course in pineapple production. Agr. Conf. Hawaiian Pineapple Packers' Assoc., Honolulu, T. H., 1 : 39–46. 1921.
7. MAGISTAD, O. C., and FARDEN, C. A. Experimental error in field experiments with pineapples. Jour. Amer. Soc. Agron., 26 : 631–644. 1934.
8. SAKURAI, YOSHIJIRO. The results gained by the use of paper mulch and straw mulch in the fruit tree industry. Jour. Soc. Trop. Agr., 3 : 85–102. 1931.
9. SCOTT, HERSCHEL. The influence of wheat straw on the accumulation of nitrates in the soil. Jour. Amer. Soc. Agron., 13 : 233–258. 1921.
10. SNEDECOR, GEORGE W. Calculations and Interpretation of Analysis of Variance and Covariance. Ames, Iowa : Collegiate Press, Inc. 1934.
11. VEIHMEYER, F. J., OSERKOWSKY, J., and TESTER, K. B. Some factors affecting the moisture equivalent of soils. First Intern Congress Soil Sci., 1 : 512–534. 1927.

FURTHER WORK WITH THE CUNNINGHAMELLA PLAQUE METHOD OF MEASURING AVAILABLE PHOSPHORUS IN SOIL[1]

A. Mehlich, E. B. Fred, and E. Truog[2]

FOLLOWING the first report (5)[3] on the Cunninghamella plaque method of measuring available phosphorus in soil, additional investigations were made in an attempt to improve the test and study its application. This report gives some of the results of these investigations, including a description of a new culture dish, comparisons of results with field tests comprising a variety of soil types and crops, and a comparison of results with Neubauer's seedling method.

THE NEW CULTURE DISH

In the test with the soil placed in small petri dishes, the maintenance of a uniform moisture content of the soil during incubation was difficult; the accurate measurement of the diameter of fungus growth was interfered with by the development of the natural fungus flora, especially when incubated for more than 48 hours; and more soil than is always desirable was required for making tests. After various trials, a new type of clay culture dish was designed which overcame these shortcomings to a large degree. This special dish[4] (Fig. 1) consists of a clay slab (55 mm in diameter by 15 mm thick) having a cavity (23 mm in diameter by 7 mm deep). The surface of the cavity is glazed so as to be waterproof, but the rest of the slab is unglazed and has a porosity of 8 to 10% so that it will hold moisture and thus promote the growth of the fungus uniformly over its surface. The surface of the unglazed portion of the dish is of dark color, such as dark red, in order that it may serve as a good background against which the white mycelium may be easily seen.

NOTES ON PROCEDURE

The procedure still followed for testing the phosphorus needs of soils is much the same as previously described (5), except that with the new type of culture dish only one-fifth as much soil and nutrient solution is needed. For the most satisfactory results, experience has shown that the following points should be observed:

Fungus cultures.—Reserve stocks, carried on malt extract-agar slants (2.5% malt extract, 2% agar), should be transferred every 4 months and kept in a cool place (2). The spore suspensions for inoculation are prepared from fresh malt

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[2] Research Assistant and Professors of Agricultural Bacteriology and Soils, respectively. The authors are indebted to a number of investigators at various agricultural experiment stations for supplying many of the soil samples used in these studies.

[3] Figures in parenthesis refer to "Literature Cited," p. 831.

[4] This special dish may be purchased of the Coors Porcelain Company, Golden, Colorado.

extract-agar slant cultures. The age of these cultures should be at least 1 week and not more than 4 weeks.

Plaque preparation.—The amount of nutrient solution needed varies with the soil; an excess should be avoided, the optimum being the point at which the soil particles just adhere to each other. The soil, well mixed with the nutrient solution, is packed into the cavity of the dish with a spatula, the surface smoothed and pressed just slightly below the rim of the cavity. Care should be taken not to smear soil over the unglazed surface. The use of dry culture dishes helps in this respect. The pan in which the dishes or plaques are placed should be adequately supplied with water, that is, filled to a depth of 6 to 8 mm.

Period of incubation.—For peats and mucks, incubation should be extended from the usual 48 hours to 72 hours, because some of the available phosphorus in organic form is not fully utilized in 48 hours.

Making readings.—A pair of calipers is useful in measuring the diameter of the growth. Several readings should be made and measurements should include only the main or actual body of the growth, ignoring a few individual hyphae which project beyond the main mass.

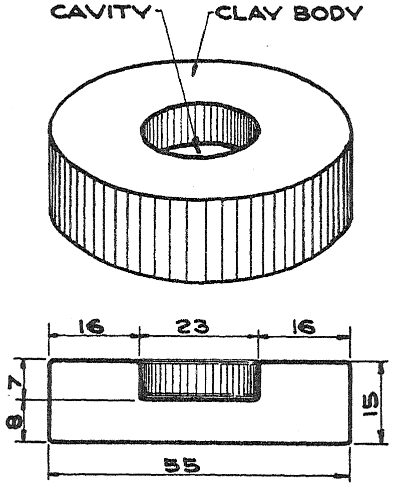

FIG. 1.—New culture dish.

Calcareous soils.—If *C. blakesleeana* is used instead of *C. elegans*, calcareous soils need not be neutralized. However, if this is done, the growth indicating adequacy of phosphate is changed from a 22 mm diameter to a 16 mm diameter.

COMPARISON OF RESULTS WITH FIELD TESTS

Using the special clay dishes and *C. blakesleeana* minus strain, we made tests on soils which had received different phosphorus treatments in the field and for which the yields of different crops were available. The soils were obtained from widely different localities in the United States and from Rothamsted, England. The majority of these soils had been under observation in the field for many years. The crop yields and fertilizer treatments were taken from station reports (1, 3, 4, 6, 7, 8, 9, 11), or the information was privately communicated. The results given in Table 1 represent only a portion of the tests made.

In general, the results indicate that phosphorus fertilization is beneficial when the available phosphorus supply produces a fungus growth of less than 22 mm in diameter. At a growth of 22 to 24 mm in diameter, apparently the yields of small grains, corn, grasses, and potatoes are no longer benefited by phosphorus applications. The *Leguminosae* and the root crops are also benefited by application of phosphorus if the soil in which they are to be grown supports a fungus

TABLE 1.—*Growth of Cunninghamella and crop yields on phosphated and non-phosphated soils and results with chemical method.*

Kind of soil	Amount of readily available phosphorus, Truog chemical method, p.p.m.		Diameter of lateral growth of *Cunninghamella*, mm		Crop yields and increases per acre on treated and untreated fields					
	Non-phosphated	Phosphated	Non-phosphated	Phosphated	Non-phosphated	Phosphated	Increase	Non-phosphated	Phosphated	Increase
						Corn, bu.			Oats, bu.	
Volusia silt loam	10	24	7	24	14.0	22.0	8.0	11.0	15.0	4.0
Hagerstown silt loam	18	40	11	24	19.1	35.8	16.7	26.3	34.5	8.2
Muscatine silt loam	18	215	14	35	36.0	59.0	23.0	34.0	48.0	14.0
					22.0	37.0	15.0	28.0	44.0	16.0
						Wheat, bu.			Clover, tons	
Wooster silt loam	8	14	10	20	8.0	18.0	10.0	0.6	1.0	0.4
Miami silt loam	4	15	12	28	11.0	19.0	8.0	0.9	1.3	0.4
Broadbalk field	27	235	12	34	12.0	21.0	9.0		Barley, bu.	
Stockyard field	19	66	16	46	10.0	16.0	6.0	11.0	16.0	5.0
Stockyard field	20	64	18	44		Alfalfa, tons				
Miami silt loam	18	32	25	38	3.5	3.8	0.3	—	Beets, tons	
						Soybeans		5.1	25.6	20.5
					3.4	6.7	3.3			
						Carrots			Cabbage	
Merrimac silt loam	21	90	16	50	11.6	14.6	3.0	1.0	7.1	6.1
						Tomatoes			Potatoes, bu.	
					7.9	9.8	1.9	244.0	305.0	61.0
							Various garden crops			
						Early varieties*			Late varieties, tons†	
Silt loam	60	88	23	45	4.0	6.0	2.0	5.7	10.7	5.0
						Potatoes, bu.			Onions, bu.	
Peat (old)	30	72	17	41	280.0	400.0	120.0	10.8	22.5	11.7
Peat (new)	25	58	12	30	210.0	380.0	170.0	8.4	21.3	12.9
Muck (old)	96	230	28	42	—	—	—	15.9	16.3	0.4
Muck (new)	50	205	15	42	—	—	—	18.1	19.3	1.2

*Peas, beets, green beans, leaf lettuce.

†Spinach, cauliflower, pepper, carrots.

growth of 26 to 28 mm in diameter; and most garden crops benefit from phosphorus if the soil supports a fungus growth of 30 mm or less in diameter. No crop was found to respond to phosphorus fertilization if the soil in which it was grown permitted a growth of more than 36 mm in diameter.

As previously shown, $CaCO_3$ influences the availability of phosphorus, and hence the growth of the fungus. To overcome this influence, it was recommended that the soil be neutralized with citric acid. This is objectionable in that the natural soil conditions are changed, and in addition it is not always possible to neutralize the soil within certain prescribed limits.

It has been noted that *C. blakesleeana* showed considerably better growth on calcareous soils than *C. elegans*. Using the former fungus, we tested a number of soils containing different amounts of $CaCO_3$ and showing a variation of response to phosphorus fertilization in the field. The results, given in Table 2, show evidence that *C. blakesleeana* may be successfully employed in testing calcareous soils without pre-treatment with acid. From these results the general inference can be made that a phosphorus need is indicated when the diameter of growth is less than 16 mm. This will vary somewhat with the plant grown. Alfalfa, especially, when grown on soils with a fertile subsoil, may not suffer for lack of phosphorus even in case the growth of *Cunninghamella* is only 13 to 14 mm in diameter.

COMPARISON OF RESULTS WITH THOSE OF NEUBAUER'S METHOD

In Table 3 results are given comparing *Cunninghamella* and Neubauer values[5] on 40 soils which differ greatly in reaction, texture, and phosphorus supply. For soils having Neubauer values above 5 mgm of P_2O_5 per 100 grams of soil, which according to Neubauer is approximately the border line dividing soils that need phosphorus fertilization from those that do not, depending, however, somewhat on the crop grown, the diameter values of *Cunninghamella* are greater than 25 mm. In the case of the lower Neubauer values, the growth of the fungus is also small. Between these extremes the agreement is more variable. Results of Truog's chemical method (10) show, in general, good agreement with both biological tests.

SUMMARY

A special clay culture dish has been designed for conducting the *Cunninghamella* test for available phosphorus of soils. This dish has the advantage of being more durable than the small glass petri dish, and its use makes the results more accurate and satisfactory. This dish was used in testing a great variety of soils, and the results obtained agree quite satisfactorily with crop yields in the field and with the results of the Neubauer and chemical methods.

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[5] Neubauer values furnished by S. F. Thornton of Purdue University.

TABLE 2.—*Growth of Cunninghamella and crop yields on phosphated and non-phosphated calcareous soils and results with chemical method.*

Soil No.	Calcium carbonate content	Amount readily available phosphorus Truog chemical method		Diameter of lateral growth of *Cunninghamella*		Crop yields and increases per acre on treated and untreated fields		
		Non-phosphated	Phosphated	Non-phosphated	Phosphated	Non-phosphated	Phosphated	Increase
	per cent	p.p.m.	p.p.m.	mm.	mm.	tons	tons	tons
							Alfalfa	
247	3.85	15	56	12	20	1.2	1.9	0.7
251	2.31	110	150	14	28	1.2	1.8	0.6
253	8.67	74	80	9	17	1.3	2.3	1.0
255	6.12	37	47	7	19	2.3	4.4	2.1
113	2.03	26	—	15	23	5.0	5.0	0.0
							Beets	
330	6.80	135	150	12	21	12.6	14.6	2.0
325	2.50	130	170	12	21	11.6	25.0	13.4
328	7.70	24	49	14	22	12.8	16.8	4.0
327	3.50	150	187	29	37	16.8	17.0	0.2
121	3.77	62	—	27	32	23.0	23.0	0.0
							Wheat	
						bu.	bu.	bu.
329	1.50	100	141	17	20	35.0	35.0	0.0
							Barley	
324	0.34	160	178	31	38	55.0	55.0	0.0
326	20.00	15	21	7	12	32.0	63.0	31.0
							Sweet Clover	
						Straw-Seed	Straw-Seed	Straw-Seed
						pounds	pounds	pounds
249	37.66	8	12	7	11	1180– 172	4880– 750	3700–578

TABLE 3.—*Level of readily available phosphorus of 40 soils as revealed by Cunninghamella, Neubauer, and chemical tests.*

Soil No.*	pH	Available phosphorus		*Cunninghamella* method, diameter of lateral growth, mm
		Truog chemical method, p.p.m.	Neubauer method, mgm P_2O_5 per 100 grams soil	
430	5.5	17	0.0	5
1752	5.7	8	0.7	8
1798	6.0	5	0.8	8
1740	4.3	8	1.0	12
1589	5.9	80	1.4	14
1640	5.7	36	1.6	12
1753	5.5	9	1.7	11
1844	4.7	7	1.8	11
1738	4.4	18	1.9	15
1739	4.0	9	2.0	14
211	7.5	20	2.1	8
1636	5.7	17	2.2	13
1643	5.6	16	2.3	16
1648 M	7.3	68	2.4	16
1644	5.7	14	2.6	15
1635	5.2	14	2.7	13
1756 M	6.2	19	2.9	10
1737	4.5	24	3.0	15
1632	4.7	10	3.3	15
1849	7.8	27	3.5	17
1638	5.9	84	3.6	21
1650 M	7.6	19	3.7	14
1588 P	6.9	32	4.0	16
1645	5.9	38	4.1	21
1846	7.6	162	4.2	16
1847	7.7	122	4.3	15
1845	6.8	34	4.5	17
1631	5.3	29	4.8	23
1593 M	5.4	155	5.0	28
1590 P	5.6	75	5.5	49
1637	5.8	88	6.1	29
1576 M	5.6	76	6.4	34
1586 P	5.5	170	6.5	50
1848	7.8	55	10.5	31
1582 P	6.1	115	10.7	53
212	5.7	92	11.0	46
1584 P	6.2	113	11.9	51
1592 P	5.2	79	12.2	44
1850	6.7	150	14.3	45
1580 P	6.4	180	15.0	54

*M = Muck. P = Peat.

LITERATURE CITED

1. DeTurk, E. E., Bauer, F. C., and Smith, L. H. Lessons from the Morrow plots. Ill. Agr. Exp. Sta. Bul. 300:107–140. 1927.
2. Greene, H. C., and Fred, E. B. Maintenance of vigorous mold stock cultures. Ind. Eng. Chem., 26:1297–1299. 1934.
3. Hartwell, B. L., and Damon, S. C. The degree of response of different crops to various phosphorus carriers. R. I. Agr. Exp. Sta. Bul. 209:1–19. 1927.
4. Lloyd, J. W., and Lewis, E. P. Fertilizer experiments with ten market-garden crops in Cook County, Illinois. Ill. Agr. Exp. Sta. Bul. 377:1–36. 1932.

5. MEHLICH, A., FRED, E. B., and TRUOG, E. The *Cunninghamella* plaque method of measuring available phosphorus in soil. Soil Science, 38:448–558. 1934.
6. NOLL, C. F., GARDNER, F. D., and IRVIN, C. J. Fiftieth Anniversary of the general fertilizer tests 1881–1931. Penn. Agr. Exp. Sta. Bul. 264:1–24. 1931.
7. ODLAND, T. E., DAMON, S. C., and TENNANT, J. L. Fertilizer and crop rotation experiments. R. I. Agr. Exp. Sta. Bul. 224:1–42. 1930.
8. ROTHAMSTED EXPERIMENT STATION REPORT, 1927–28. Harpenden, England. 1929. (176 pages.)
9. THORNE, C. E. The maintenance of soil fertility. Ohio Agr. Exp. Sta. Bul. 381:245–354. 1924.
10. TRUOG, E. The determination of the readily available phosphorus of soils. Jour. Amer. Soc. Agron., 22:874–882. 1930.
11. WHITE, J. W., and GARDNER, F. D. Soil fertility experiments on Volusia and Westmoreland soils. Penn. Agr. Exp. Sta. Bul. 229:1–31. 1928.

IMMEDIATE EFFECTS OF FERTILIZATION UPON SOIL REACTION[1]

C. B. CLEVENGER AND L. G. WILLIS[2]

IT has long been observed that some fertilizer materials, after a period of continual use, have a marked effect upon the reaction of the soil. Ammonium sulfate ultimately increases the soil acidity, while sodium nitrate has the reverse effect. According to Pierre (1),[3] the organic ammoniates are acidifying agents, but Plummer (2) has reported results showing an alkaline effect of dried blood after several years of use. A change in soil reaction is often not desirable and especially so when the reaction already approaches that which under the prevailing soil and climatic conditions seems best for the production of the crop that is to be grown.

Due to the increased manufacture and use of ammonium salts during the last 25 years much attention has recently been given by various investigators to the acid- or base-forming properties of fertilizers. The work of Pierre (1) in formulating a laboratory method for the determination of the acid- or base-forming property of fertilizers has provided a means whereby these properties can be expressed quantitatively in terms of calcium carbonate equivalent. Manufacturers are now enabled to place on the market fertilizers which are non-acid-forming by the substitution of the proper amounts of basic materials for a part of the filler.

Pierre's factors relate only to the ultimate effects upon soil reaction. While these are important, intermediate effects also should be considered. In the case of organic ammoniates there is evidence that in the process of ammonification intermediate alkaline effects of significance may be produced. Since the reaction of the soil, or factors associated with it, is often of prime importance in the production of crops, it seems reasonable to believe that temporary or intermediate effects of fertilizers upon the reaction of the soil may play a greater part in the plant-soil relationship than at present suspected.

ALKALINITY PRODUCED BY AMMONIFICATION

Willis and Rankin (5) have shown that organic forms of nitrogen become converted into ammonia so rapidly in the soil as to produce injury on cotton seedlings. In some later work,[4] a measure of the amount of this conversion was obtained by placing ammonifying cultures within closed containers which were held at constant temperature and pressure. With 300 milligrams of nitrogen in the form of

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[2] Professor of Soils, North Carolina State College, and Soil Chemist, North Carolina Agricultural Experiment Station, respectively.

[3] Figures in parenthesis refer to "Literature Cited," p. 846.

[4] Unpublished data presented at the meeting of Section O, A. A. A. S., Atlantic City, N. J., 1932, by L. G. Willis.

cottonseed meal in a medium of Norfolk sand, ammonia formation was rapid throughout a period of 16 days during which time nearly half of the total nitrogen of the cottonseed meal was ammonified. The conversion was accelerated by the addition of calcium sulfate to the cultures (Fig. 1).

The pH of the cultures increased rapidly reaching a constant value in 8 days. In the cultures without calcium sulfate the maximum pH was about 8.5, whereas with calcium sulfate the maximum was about 8.0 (Fig. 2). Determinable amount of ammonia were found in the atmosphere above the cultures, the concentration being greatest where the calcium sulfate was omitted (Fig. 3).

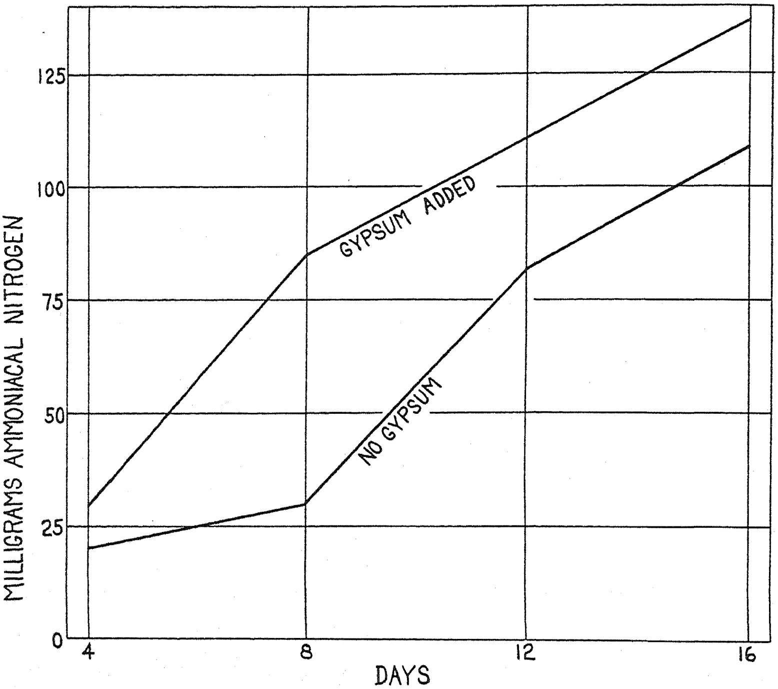

Fig. 1.

EFFICIENCY OF ORGANIC AMMONIATES

The rapid attainment of these alkaline values suggested the possibility that, while organic ammoniates are ultimately acid forming, there might be an initial neutralizing effect of appreciable magnitude due to formation of ammonia soon after the fertilizer containing these materials was applied to the soil.

If such an effect was evident, a question might be raised as to the significance of this property of the organic ammoniates as they are commonly used in fertilizers. It has long been considered that the value of organic materials lies in the fact that they provide a source of nitrogen that becomes available slowly throughout the season of crop growth.

The validity of this opinion is subject to considerable doubt in view of the evidence of rapid conversion of organic nitrogen into ammonia.

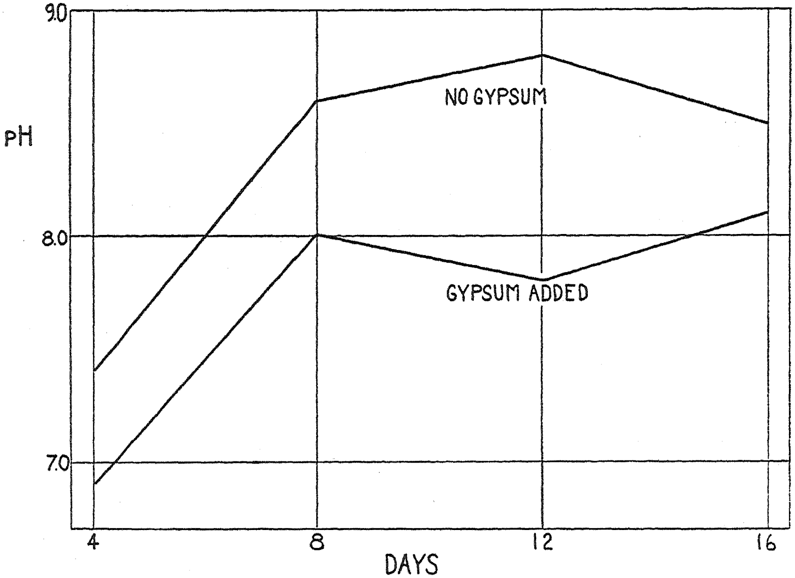

FIG. 2.

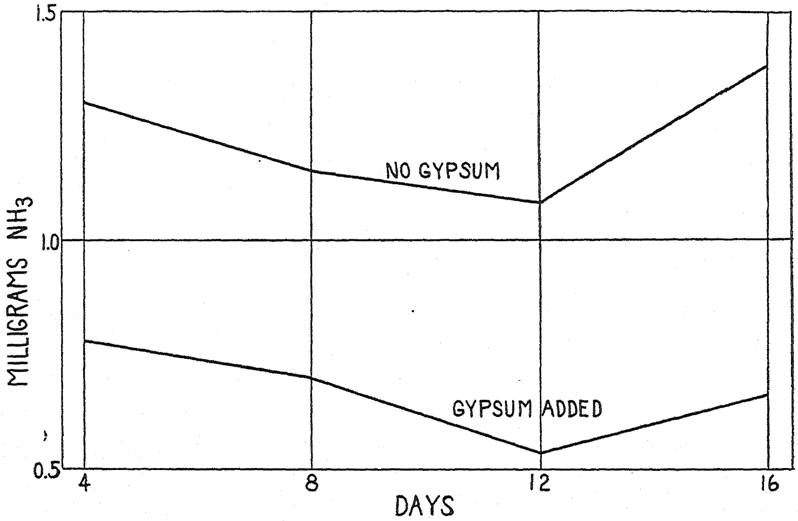

FIG. 3.

The object of the work to be presented here is to determine the magnitude of the early neutralizing effect of the organic ammoniates, cottonseed meal and urea, in comparison to that of dolomitic limestone used at rates calculated to produce a non-acid-forming fertilizer.

PLAN AND PROCEDURE OF THE WORK

Complete fertilizers of various formulas were mixed in potted soils, kept at a constant temperature of 25°C and moisture content of 50% of the saturation capacity, and the trends of the soil reaction were followed by making pH determination of the soil at frequent intervals. The quinhydrone electrode was used for the determination of the pH values immediately after the fertilizers were mixed with the soil and thereafter during a period of 4 to 5 weeks following the fertilizer applications.

Four different soils were used, a Coxville fine sandy loam and a Norfolk sandy loam from the Coastal Plain, the former being well buffered with organic colloids, and Durham and Cecil sandy loams from the Piedmont area, of which the latter was moderately buffered with mineral colloids. The soils were used as they came from the field without preliminary drying, their pH values ranging from 4.3 to 5.3. They were also limed with C. P. precipitated calcium carbonate in amounts intended to raise their pH values to between 6.0 and 7.0. Reaction trends from the same fertilizer treatments were thus obtainable for each of the soils in two different pH ranges.

The respective soils in amounts ranging from 6 to 8 pounds were put into 1-gallon glazed earthernware pots which were placed into a humified constant temperature insulated box in which air was circulated by a forced draft. All the soils both without and with added lime were kept in the constant temperature box for a week before the additions of fertilizer in order for a chemical and biological equilibrium to be established.

The fertilizer-soil mixtures were made with a ratio of 1:0.008. This is calculated from the assumption that the fertilizer would be applied at the rate of 1,000 pounds per acre, drilled in rows 6 inches wide and 4 feet apart, and the fertilizer mixed with one-half of the depth of the surface soil.

The analysis of all the fertilizers used was 3% nitrogen (N), 8% available phosphoric acid (P_2O_5), and 6% potash (K_2O). The formulas differed only in respect of the source of nitrogen. In each the potash all came from muriate of potash (51.2% K_2O) and the phosphoric acid all came from superphosphate (15.4% P_2O_5). The nitrogen came from ammonium sulfate (20.5% N), sodium nitrate (16.2% N), cottonseed meal (6.19% N), and urea (46.3% N).

The formula in which ammonium sulfate was used as the sole source of nitrogen was designated as the standard. Each of the other forms of nitrogen, sodium nitrate, cottonseed meal, and urea, were substituted for one-fourth, one-half, three-fourths, or all of the ammonium sulfate, respectively.

The substitution of the variant forms of nitrogen made 13 different formulas and all were applied to the four soils, both limed and unlimed, without and with supplements of dolomitic limestone in amounts calculated to produce a non-acid fertilizer. An outline of the fertilizer treatments is given in Table 1. Duplicate treatments were not made.

In sampling the pots for the determination of the pH of the soil, two cores of soil extending from the top to the bottom of the pot were withdrawn, mixed, and a sample taken. The remainder was returned to the pot. In maintaining the soil at the proper moisture content the weight of soil withdrawn for samples was deducted from the previous total weight. Check pots in which the soil received no addition of fertilizers were included in each series. No plants were grown in this work.

TABLE 1.—*Sources of nitrogen in fertilizer treatments.*

Formula Nos.	Source of nitrogen in fertilizer formula	
1	——————	All from ammonium sulfate
2	¼ from sodium nitrate	¾ from ammonium sulfate
3	½ from sodium nitrate	½ from ammonium sulfate
4*	¾ from sodium nitrate	¼ from ammonium sulfate
5*	All from sodium nitrate	——————
6	¼ from cottonseed meal	¾ from ammonium sulfate
7	½ from cottonseed meal	½ from ammonium sulfate
8	¾ from cottonseed meal	¼ from ammonium sulfate
9	All from cottonseed meal	——————
10	¼ from urea	¾ from ammonium sulfate
11	½ from urea	½ from ammonium sulfate
12	¾ from urea	¼ from ammonium sulfate
13	All from urea	——————
Check	Unfertilized	

*Formulas 4 and 5 are potentially alkaline and therefore did not require a supplement of dolomitic limestone.

RESULTS

The reaction trends from the different fertilizers are shown in Figs. 4 to 7. The broken line and solid line curves represent, respectively, the reaction trends with the fertilizers, without and with the dolomite supplements. The dotted lines are the curves for the untreated soils used as checks.

INITIAL DECREASE IN PH VALUES

In all cases, on mixing the fertilizers with the soil, a drop in the pH of the soil ranging from 0.6 to over 1.0 unit took place immediately. The opinion that this was primarily a salt effect was verified later when similar results were obtained from additions of superphosphate and muriate of potash to the soils in amounts equivalent to those contained in the fertilizer.

In the limed soils the initial decrease in pH was greater than that found in the unlimed soils excepting the Coxville soil in which the difference was negligible.

On the less well buffered soils of the Durham and Norfolk series without lime or fertilizer there was an unexplained trend toward lower pH values throughout the experiment. Where lime was added this trend was distinctly evident on the Cecil soil, very pronounced on the Norfolk and Durham soils, and not perceptible on the Coxville. All pH changes in the soil-fertilizer mixtures, therefore, are to be interpreted relative to those of the soil alone.

Following the initial decrease in pH due to the addition of fertilizer without the dolomite supplement, there is a slight but definite increase with formula 1 except in the Coxville soil. In the Norfolk and Durham soils this trend persists throughout the course of the experiment. In the limed soils the rise in pH is not so pronounced after the first few days.

The effect of sodium nitrate is virtually identical with that of ammonium sulfate in all soils both without and with lime. It appears, therefore, that under the conditions of this experiment and within

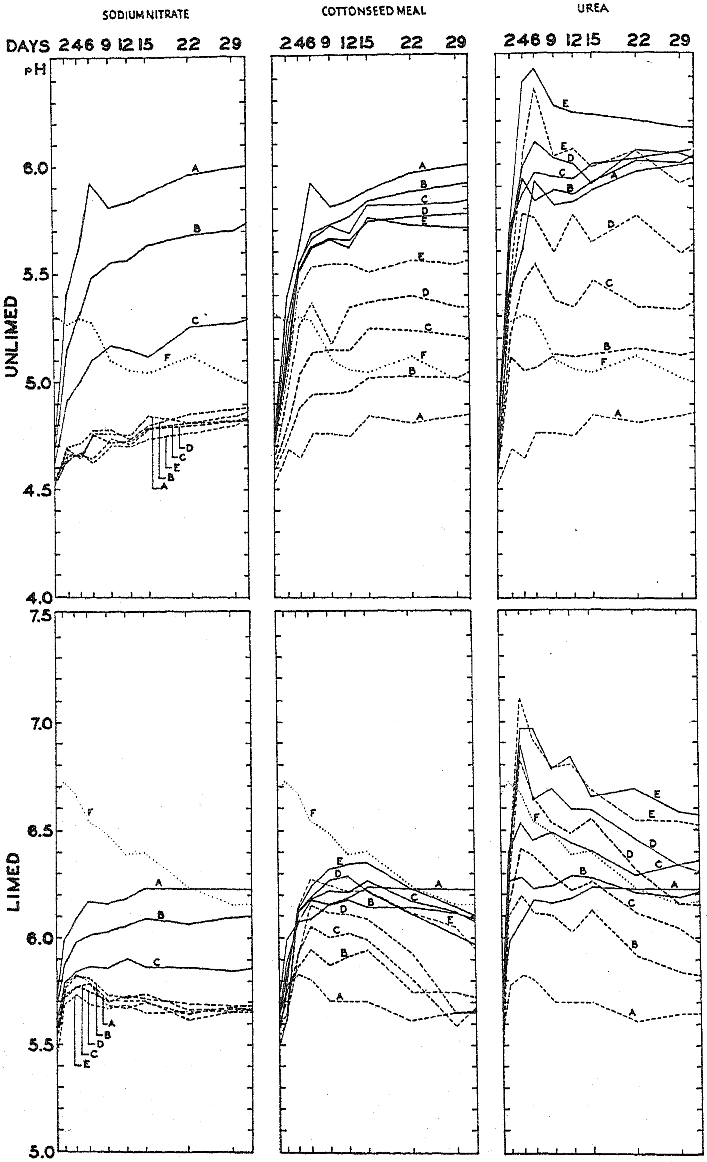

FIG. 4.—Durham sandy loam.

Broken lines, fertilizers without dolomitic limestone; solid lines, fertilizers supplemented with dolomitic limestone; dotted lines, unfertilized or check. Curves, A, all ammonium sulfate; B, three-fourths ammonium sulfate; C, one-half ammonium sulfate; D, one-fourth ammonium sulfate; E, no ammonium sulfate; and F, check.

a period of 30 days any acidity or alkalinity that might develop from these two materials must depend upon the utilization by plants of anionic or cationic nitrogen from the two compounds.

INCREASES IN pH VALUES WITH DOLOMITE SUPPLEMENTS

In the fertilizers containing ammonium sulfate and sodium nitrate with dolomitic limestone supplements, there was a rapid increase in pH reaching a virtual maximum at 10 to 15 days and thereafter a more gradual rise relative to the unfertilized soils. The extent of the rise was proportional to the amount of dolomite or to the amount of ammonium sulfate. It is doubtful that there is any significance in the latter relationship, however, since the salt concentration was maintained by the sodium nitrate which was substituted for the ammonium sulfate and these mixtures had virtually identical effects when used without the dolomite.

EFFECT OF COTTONSEED MEAL ON pH

When cottonseed meal was substituted for ammonium sulfate in the unlimed soils there was an extremely rapid increase in pH during the first 3 days followed by a further slow increase for the entire period relative to the unfertilized soil. Without the dolomite the increase in pH was proportional to the amount of cottonseed meal used, each successive increment producing an increase of 0.1 to 0.2 pH.

In the less well buffered soils without lime the order of the relation between the content of cottonseed meal and pH increase is generally reversed with the fertilizers having dolomitic supplements, indicating a somewhat greater neutralizing value for the dolomite supplement than for the ammonia produced by ammonification. There was little difference in the trends of the two types of fertilizer during the whole period except for greater pH values in those with the dolomite supplements, with which a lesser difference due to the form of nitrogen used was noted.

NEUTRALIZING EFFECT OF UREA

All effects noted with urea in the fertilizers were similar to those of the corresponding cottonseed meal formula, but more pronounced, with the exception that the ammonia formed from urea was a more active neutralizing agent than was the dolomite supplement. Maximum pH values were reached more promptly with the urea. In the Cecil soil this was accomplished within 24 hours when all the nitrogen was supplied as urea. In the fertilizers without dolomite supplements a greater pH range was found than with the cottonseed meal, whereas, with the dolomite supplement the range with the urea was less.

TRENDS IN LIMED SOILS

Relative to the pH values of unfertilized soil, none of the fertilizer formulas gave evidence of as great a neutralizing effect in the limed soil as was found in the corresponding soil unlimed, nor was the range of pH values produced by the organic ammoniates without dolomite as great in the limed soils as in those without lime.

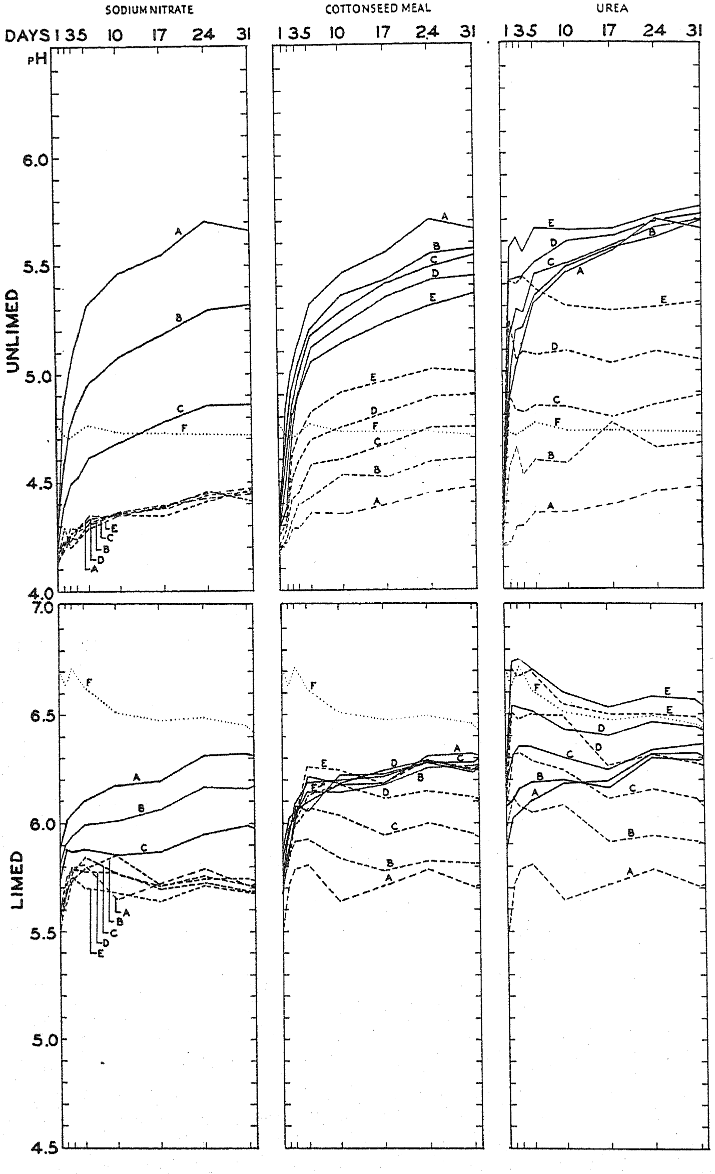

FIG. 5.—Cecil sandy loam.

Broken lines, fertilizers without dolomitic limestone; solid lines, fertilizers supplemented with dolomitic limestone; dotted lines, unfertilized or check. Curves, A, all ammonium sulfate; B, three-fourths ammonium sulfate; C, one-half ammonium sulfate; D, one-fourth ammonium sulfate; E, no ammonium sulfate; F, check.

As was found in the unlimed soils, the fertilizers containing ammonium sulfate and sodium nitrate were virtually identical in their effect on the pH values when no dolomite supplement was included. With the dolomite, however, there was a sharp initial increase in pH followed by a slowly rising trend. With the organic ammoniates, however, both without and with the dolomite supplements there was a pronounced tendency to a decrease in pH after the early rise. This downward drift was proportional to the amount of organic ammoniate in the formula and more pronounced with urea than with cottonseed meal.

In the Coxville soil no fertilizer formula gave a pH greater than that of the unfertilized soil. In the other soils without added lime all fertilizers with dolomite supplements and all fertilizers with one-half or more of the nitrogen from the organic forms gave greater pH values than those of the respective unfertilized soils. In the limed soils the neutralizing value of the dolomite supplements was less pronounced, cottonseed meal raised the pH above that of the unfertilized soil only on the Norfolk sandy loam, and urea gave a distinct increase in pH over that of the unfertilized soil only on the poorly buffered Norfolk and Durham sandy loams.

RELATIVE NEUTRALIZING EFFECTS OF COTTONSEED MEAL AND UREA

An interesting comparison between cottonseed meal and urea is shown in the results on all but the Coxville soils where the pH differences are too small to be considered significant. In the unlimed soils the virtual maximum pH value reached by the fertilizers containing all the nitrogen as cottonseed meal without dolomite was attained in 5 to 7 days and was approximately the same as that found in the corresponding treatments where urea was the source of one-half of the nitrogen. The urea, however, gave maximum pH values in 1 to 6 days. From the trend of the curves of the urea formulas it appears that all the nitrogen of this compound had been converted to ammonia within these periods. It would seem, therefore, that within a week under the conditions of this experiment one-half of the cottonseed meal had been converted into ammonia.

AMMONIFICATION OF UREA

It would be expected that urea in its original form would be readily leached from the soil. The actual risk of loss by this means is negligible, however, in view of the evidence of an extremely rapid conversion to ammonia in the soil.

It was impossible to determine the course of ammonification and nitrification in these soils but, at the expiration of the work, nitrates were determined. In only a few random cases was there any evidence of the nitrification of materials added in the fertilizers. No explanation can be offered, therefore, for the gradual decreases in the pH values of the unfertilized Norfolk and Durham soils, nor for the almost parallel decreases with the fertilizers containing cottonseed meal and urea in these soils when limed.

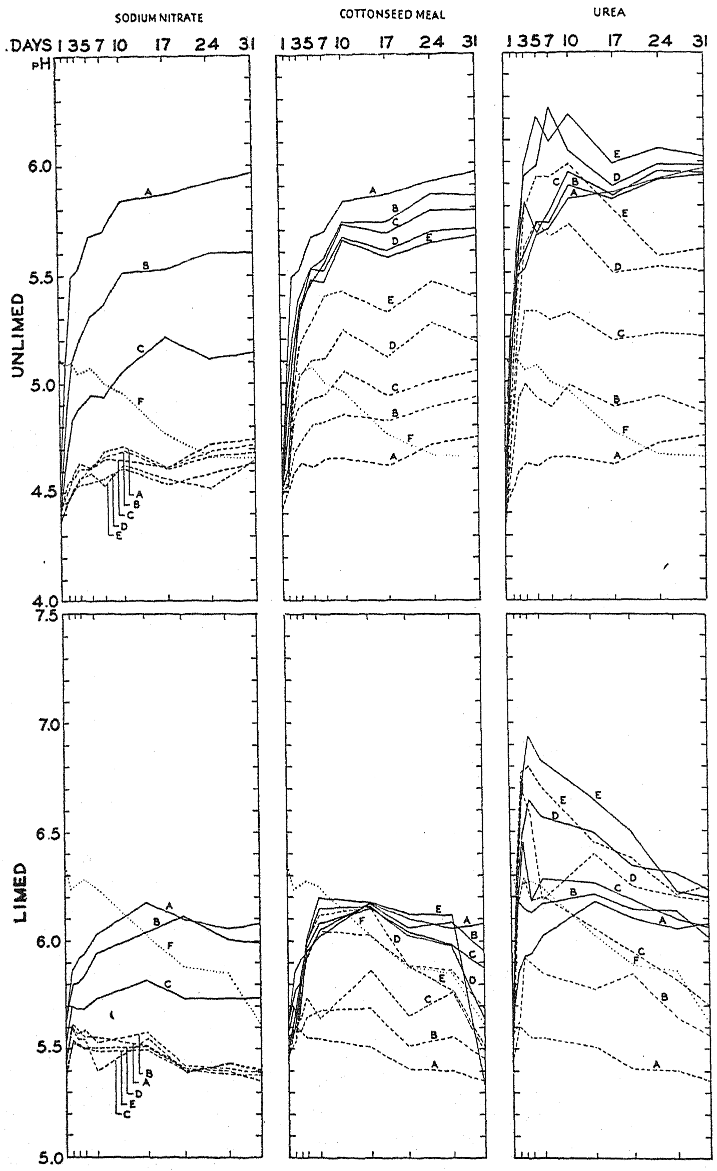

FIG. 6.—Norfolk sandy loam.

Broken lines, fertilizers without dolomitic limestone; solid lines, fertilizers supplemented with dolomitic limestone; dotted lines, unfertilized or check. Curves, A, all ammonium sulfate; B, three-fourths ammonium sulfate; C, one-half ammonium sulfate; D, one-fourth ammonium sulfate; E, no ammonium sulfate; F, check.

APPLICABILITY OF RESULTS

It is evident that within a month after the application of fertilizers the organic ammoniates can serve as neutralizing agents almost as extensively as can a dolomite supplement. The physiological effects of the two methods of neutralization are not equivalent however. Tiedjens and Robins (3) have shown that ammonium nitrogen is most available at the higher pH levels. From a nutritive standpoint, therefore, it would make little difference whether the pH was reached by the use of a lime supplement to the fertilizer or by the ammonification of the organic materials.

It should be understood that these results were obtained at a constant soil temperature of 25°C. This condition was imposed by the facilities available. At other temperatures the rates of ammonification and of reaction of the dolomite supplement would differ from those observed in this work. The salt effect on pH would probably be influenced to a negligible degree by temperature.

In soils at lower temperatures than 25°C, therefore, the natural organic forms of nitrogen would have a lesser rate of neutralization of soil acidity and would act as slowly available sources of nitrogen. The rate of neutralization by the dolomite supplement should also be slower in the cooler soils. The effect of soil temperature on the ammonification of urea is difficult to predict in view of the evidence that this conversion appears not to be directly biological in nature.

It would appear from general consideration, therefore, that fertilizers should be formulated with regard to the temperatures of soils in which they are to be used, particularly with reference to the acidity-basicity factors.

The ammonia injury factor (4) would, however, be most pronounced with the organic materials inasmuch as the lime supplement would supply calcium and magnesium for the prevention of the injury. There are limits to this protective effect, however, and calcium and magnesium salts cannot fully prevent ammonia injury if the concentration of the latter component of the fertilizer exceeds the limits of tolerance exhibited by the plants (5).

In consideration of the more rapid ammonification of urea it would seem that the tolerance to this material should be less than that of cottonseed meal or similar organic ammoniates when equivalent amounts of nitrogen are involved. From the data it would appear that the nutritive and also the injury values of urea would be about twice those of the natural organic materials.

It is customary to evaluate fertilizer materials relative to their effects when used with superphosphate containing an abundance of calcium salts. In fertilizers containing relatively low concentrations of calcium the tolerance of plants to the organic ammoniates would be greatly lessened and it is doubtful that the calcium or magnesium from limestone supplements alone would appreciably correct the ammonia injury factor.

It is commonly stated that the value of the natural organic material lies in the property of becoming available slowly and furnishing a supply of nitrogen throughout the growing season. This supposed virtue is debatable in view of the evidence that fully one-half of the nitrogen from cottonseed meal is converted to ammonia within 2

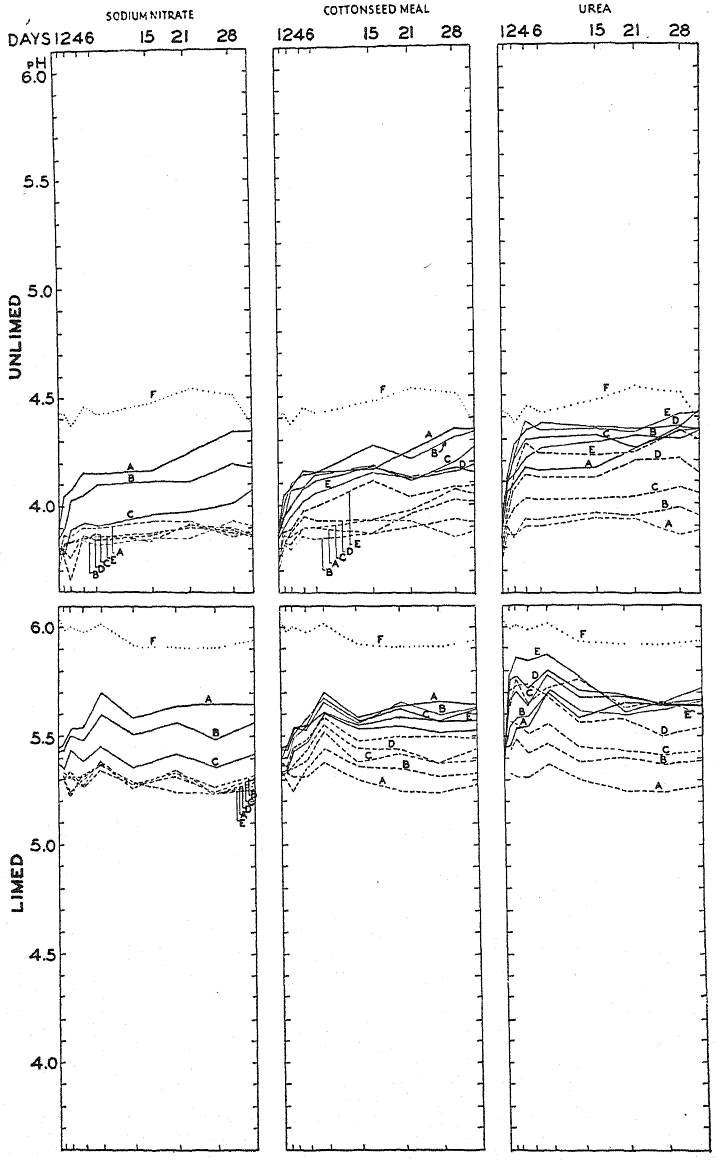

FIG. 7.—Coxville sandy loam.

Broken lines, fertilizers without dolomitic limestone; solid lines, fertilizers supplemented with dolomitic limestone; dotted lines, unfertilized or check. Curves, A, all ammonium sulfate; B, three-fourths ammonium sulfate; C, one-half ammonium sulfate; D, one-fourth ammonium sulfate; E, no ammonium sulfate; F, check.

weeks after addition to the soil. Furthermore, the rate of application of the fertilizer is involved. If, for example, it should be found in experimentation that a fertilizer containing 4% of nitrogen applied at a rate of 600 pounds to the acre is most efficient when one-fourth of the nitrogen is derived from organic sources, it does not follow that this ratio is the optimum for other rates of application. In the former case there would be supplied 6 pounds of nitrogen to the acre from the organic materials. If one-half of this becomes available within 2 weeks, there would remain for use by the crop during the remainder of the season only 3 pounds of nitrogen.

If the virtue of the organic ammoniates should lie in the neutralizing value of the ammonia produced on decomposition, the rate of application would constitute a variable relative to efficiency that could not be controlled in practice.

The similarity between urea and cottonseed meal in regard to ammonia production would indicate, however, that the urea could be substituted wholly or in part for the high grade natural organic ammoniates in all fertilizers supplying nitrogen to the soil in amounts that would furnish negligible quantities of slowly available nitrogen. The difference in cost of the two classes of materials would then constitute a practical consideration inasmuch as those who apply fertilizers at less than the rates used in experimentation would pay little premium for fertilizers containing urea, while those who practice more liberal fertilization would suffer little or no loss due to the difference in the efficiency of the two classes of materials. These assumptions are based on the hypothesis, supported by the evidence in this work, that an important function of the whole group of organic ammoniates is to accomplish the prompt neutralization of the acidity developed immediately upon the addition of fertilizer to the soil.

SUMMARY

A study was made of the early neutralizing effect of the organic ammoniates, cottonseed meal, and urea in comparison to that of dolomitic limestone used at rates calculated to produce a non-acid-forming fertilizer.

Complete fertilizers of various formulas (13 in number) were mixed in potted soils which were kept at a constant temperature and moisture content and the trends of the soil reaction were followed by making pH determinations of the soil at frequent intervals. The analysis of all the fertilizers was 3-8-6. The potash and phosphoric acid in all formulas came from the same sources. The nitrogen was supplied by ammonium sulfate alone and mixed with sodium nitrate, cottonseed meal, or urea. These fertilizers were applied to four soils at two different pH ranges, without dolomitic limestone supplements and with dolomitic limestone supplements in amounts calculated to produce non-acid-forming fertilizers. The soils were used as they came from the field and after treatment with additions of lime (precipitated calcium carbonate) intended to give a pH value of the soil between 6.0 and 7.0.

In all cases on mixing the fertilizers with the soil, a drop in the pH of the soil ranging from 0.6 to over 1.0 unit took place immediately. This drop is due to a salt effect.

The reaction trends of the various fertilizers for the soils used are very similar except for the Coxville soil in which case the magnitude of the reaction change is smaller due to a high content of organic buffering material.

In the unlimed soils for fertilizers without dolomitic supplements, the reaction trends for the fertilizers containing ammonium sulfate and sodium nitrate are virtually identical, there being generally a slight rise in pH following the initial decrease. For fertilizers containing cottonseed meal and urea the rise in pH was significant and was proportional to the amounts of these materials in the fertilizers. The increases in pH were rapid during the first few days followed by a further slow increase for the entire period relative to the unfertilized soil. Maximum pH values of the soil were reached in 1 to 6 days with urea and in 5 to 6 days with cottonseed meal.

With dolomitic limestone supplements (unlimed soil), the ammonium sulfate fertilizers gave a pH rise greater than that of the sodium nitrate or cottonseed meal fertilizers. It was surpassed only by the pH rise for the fertilizers containing the larger increments of urea.

Relative to the pH values of unfertilized soil, none of the fertilizer formulas gave evidence of as great a neutralizing effect in the limed soil as in the corresponding soil unlimed, nor was the range in pH values produced by the organic ammoniates without dolomite as great as in the unlimed soils.

The maximum pH values reached by the fertilizer in which all the nitrogen was in the form of cottonseed meal without dolomite was approximately the same as that found in the corresponding treatment where urea was the source of one-half of the nitrogen. Assuming that the urea was ammonified within a period of a week under the conditions of the experiment, it seems that one-half of the cottonseed meal was ammonified within this period.

For a period after the application of fertilizers the organic ammoniates can serve as neutralizing agents almost as extensively as can a dolomite supplement.

Results in this work indicate that the value of natural organic ammoniates as they are used in mixed fertilizers does not lie solely in the property of becoming available slowly and furnishing a supply of nitrogen throughout the growing season. An important function of the whole group of organic ammoniates, including urea, is to accomplish the prompt neutralization of the acidity developed upon the addition of a fertilizer to the soil.

LITERATURE CITED

1. PIERRE, W. H. Determination of equivalent acidity and basicity of fertilizers. Ind. and Eng. Chem., An. Ed., 5:229–234. 1933.
2. PLUMMER, J. K. Studies in soil reaction as indicated by the hydrogen electrode. Jour. Agr. Res., 12:19–31. 1918.
3. TIEDJENS, V. A., and ROBINS, W. R. The use of ammonia and nitrate nitrogen by certain crop plants. N. J. Agr. Exp. Sta. Bul. 526. 1931.
4. WILLIS, L. G., and PILAND, J. R. Ammonium calcium balance: A concentrated fertilizer problem. Soil Science, 31:5–23. 1931.
5. ———— and RANKIN, L. W. Free ammonia injury with concentrated fertilizers. Ind. and Eng. Chem., 22:1404–1407. 1930.

THE BIOLOGICAL EFFECT OF AVAILABLE PHOSPHORUS IN HAWAIIAN SOILS[1]

A. FLOYD HECK[2]

PHOSPHORUS is not only a very important plant food, but it is also one of the outstanding factors affecting the rate of biological activity in the soil. Phosphorus has usually been considered an aid to nitrification, but the effect of phosphorus on this process may be reversed by increasing the amount of available carbonaceous energy material in the soil. In this case the phosphorus also stimulates biological action, but with an entirely different set of organisms and with an entirely different effect. This increased biological action results in a more rapid utilization of mineral nitrogen by the soil microorganisms, and a more complete change of this nitrogen into organic form in the micro-organic tissue. From a practical point of view, this action of the phosphorus is distinctly beneficial in at least three ways, *viz.*, (a) the leaching of inorganic nitrogen by irrigation water is greatly reduced because of the reduction of inorganic nitrogen, (b) the availability of the nitrogen is better distributed throughout the growing season, and (c) the amount of phosphorus in the organic or biological balance is greatly increased.

EXPERIMENTAL

In June 1930, a set of plats was laid out at the Waipio Substation of the Experiment Station, Hawaiian Sugar Planters' Association, in which sodium nitrate was used in combination with molasses and with molasses and rock phosphate in the fertilization of cane. During the latter part of June, 1930, the fertilizers were applied in the line (row), the cane planted, and irrigation water applied in the normal manner. The three plats used in this connection were fertilized before planting as follows:

Plat 2. Sodium nitrate, 1,500 pounds an acre.
Plat 4. Sodium nitrate, 1,500 pounds an acre.
Waste molasses, 10 tons an acre.
Plat 15. Sodium nitrate, 1,500 pounds an acre.
Waste molasses, 10 ton an acre.
Rock phosphate, 6 tons an acre.

On September 29, and again on November 5, 1930, these plats were sampled by 12-inch depths to a total depth of 6 feet and the nitrate nitrogen determined. The results are given in Tables 1 and 2.

Nitrate nitrogen is soluble in water and remains so in the soil solution. Under irrigation the nitrate moves with the irrigation water. The downward movement, however, is usually greater than the return, with the net result that under irrigation nitrate nitrogen tends

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[1] Contribution from the Department of Soils, University of Wisconsin, Madison, Wis. Received for publication August 19, 1935.

[2] Research Associate in Soils.

TABLE 1.—*Nitrate nitrogen in the soil under growing cane at the Waipio Substation, September 29 and November 5, 1930, cane planted and fertilized the latter part of June, 1930.*

Plat No.	Nitrate nitrogen, p.p.m.							
	1st 6 in.	2d 6 in.	2d foot	3d foot	4th foot	5th foot	6th foot	Total 6 feet
				Sept. 29, 1930				
2	1.4	5.5	38.0	85.0	38.0	10.0	6.0	184.0
4	1.5	4.5	31.0	68.0	25.0	10.0	4.0	134.0
15	1.7	4.5	12.5	37.0	23.0	9.0	3.0	90.7
				Nov. 5, 1930				
2	1.2	13.0	30.0	85.0	32.0	10.0	6.0	177.2
4	2.5	3.1	3.1	32.0	59.0	11.7	3.5	123.9
15	4.4	3.0	13.0	23.0	9.2	3.4	2.1	58.1

TABLE 2.—*The effect of molasses and phosphorus on the change of inorganic nitrogen to the organic form.*

Treatment in addition to nitrogen	Inorganic nitrogen changed to the organic form	
	p.p.m.	Percentage of applied nitrogen*
	Sept. 29, 1930	
Molasses and phosphorus	93.3	50.6
Molasses	50.0	27.2
Change due to phosphorus	43.3	23.4
	Nov. 5, 1930	
Molasses and phosphorus	109.1	61.7
Molasses	43.3	24.5
Change due to phosphorus	65.8	37.2

*Based on the nitrate nitrogen found in plat 2 (nitrate alone) for each date.

to be leached into the subsoil. Fig. 1 shows that the applied nitrate in this work had moved downward over 3 feet in a period of 3 months. The extent of this movement will depend much upon the amount and frequency of irrigation, and especially upon the amount of excess irrigation water used. When sodium nitrate was used alone, practically all of the applied nitrogen was found in the soil as nitrate, but at a point 3 feet below the surface where it was applied. Where molasses was applied along with the nitrate, the sugar in the molasses caused a rapid growth of micro-organisms (1)[3] which caused part of the nitrate nitrogen to be changed to the organic form in the micro-organic tissue. The nitrogen so changed is held in the surface soil for later use by the cane. In this work the data indicate that about one-fourth of the nitrogen was held in this way as the result of the molasses alone.

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[3] Figures in parenthesis refer to "Literature Cited," p. 851.

If, in addition to the molasses, available phosphorus is also supplied, the biological action is more rapid and seems to extend over a much longer period of time, and in this experiment, resulted in the combination of as much as 60% of the applied nitrate nitrogen into micro-organic form. Thus, the use of phosphorus with the energy material of the molasses more than doubled the effectiveness of the molasses in the prevention of leaching. Phosphorus alone, however, showed very little, if any, tendency to bring about this effect. It seems from the data that the sugar in the molasses is essential in building up and maintaining a biological balance (2) and combining into organic form a large amount of nitrogen and phosphorus into the micro-organic tissue which is produced. No doubt, this is due to the rapid growth of yeasts during the decomposition of the sugars in the molasses. If the molasses is burned or treated in any way in which its sugar is destroyed, most of its biological effect is lost and its value is reduced to the mere value of the mineral salts which it contains (3).

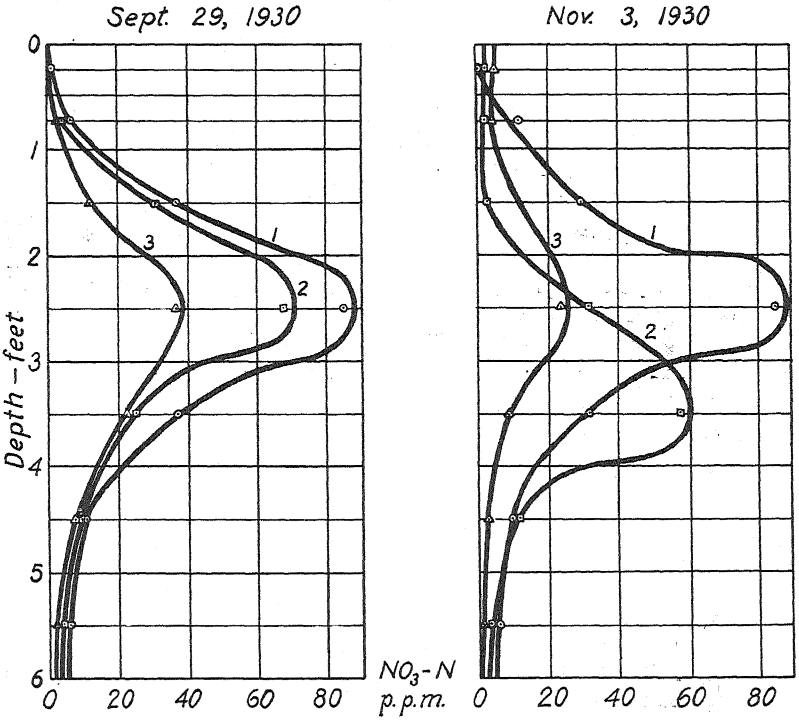

FIG. 1.—Distribution of nitrate nitrogen under lines of cane at the Waipio Substation after an application of sodium nitrate to the surface soil at planting time, June 1930, at the rate of 250 pounds of nitrate nitrogen an acre. The graphs show the effect of molasses and phosphorus on the quantity and distribution of the remaining nitrate. 1, sodium nitrate alone; 2, sodium nitrate and molasses; 3, sodium nitrate, molasses, and rock phosphate.

On November 5, the plat receiving the rock phosphate along with sodium nitrate and molasses had a higher nitrate content in the surface 6 inches than any other plat. This indicates that most of the available energy material in the molasses had been used up, and at that time, the phosphorus was aiding in the nitrification process, so that the nitrogen which had been changed to the organic form and held in the surface soil was then being slowly changed again to nitrate for use of the cane. In this way the nitrogen is held in the surface soil against leaching and also the supply of nitrate nitrogen is made more constant over a longer period of time. It is more than possible that a certain amount of phosphorus is also made available from the organic material in much the same way as is the nitrogen.

No yield data were obtained of this cane, nor were the phosphorus or potassium contents of the juice determined.[4] At the age of 7 months the plat treated with phosphorus in addition to molasses and nitrate was easily 25% better in growth of cane than either nitrate alone, nitrate and molasses, or nitrate and phosphorus. The sugar content of the cane juice was much the same for all plats at this stage of growth.

DISCUSSION

The presence of carbonaceous energy materials in the soil facilitates the growth of yeasts and fungi, and these use up nitrogen in their growth and change the soluble inorganic nitrogen in the soil to organic nitrogen in micro-organic form in the cell structure of these organisms. Available phosphorus accelerates this process and in the work reported in this paper has more than doubled the amount of mineral nitrogen changed to the organic form. In this process, phosphorus is also built up into the micro-organic tissue. There is little doubt that this phosphorus is largely organic in nature and its availability and utilization by crops must depend upon biological activity to a large extent. So long as there is available energy material present in the soil, nitrogen and phosphorus will both be changed to the organic form. As soon as this energy material is used up these organisms stop growing and an entirely different set of organisms become active. With these latter organisms, the reaction is reversed and nitrogen and phosphorus are again liberated in the inorganic form for use of the growing plant.

The nitrogen is liberated as nitrate, which is soluble in the soil solution and is either used by the plant or leached into the subsoil. The story of phorphorus, however, is entirely different. When the organic phosphorus is liberated as phosphoric acid in the soil solution it immediately becomes a part of an inorganic phosphate equilibrium which the author (4) has proposed as an explanation for the slow fixation of quickly to slowly available phosphates. In this way there is a definite relation between the phosphorus in the organic or micro-organic form and that in the inorganic form. In this relation it does not seem out of place to think of soil phosphorus as being distributed throughout a rather complex equilibrium made up of an organic or biological phase, on the one hand, and the inorganic

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[4] Work was discontinued February 10, 1931.

equilibrium or mineral phase on the other, with both phases in equilibrium biologically with each other. The direction and rate of any shift of phosphorus in this complex equilibrium will depend very much upon the rate and kind of biological activity, and this in turn on the amount and kind of carbonaceous material in the soil.

In this connection a very interesting relationship may be seen between the biological activity and the availability of the phosphorus in the soil. Since phosphorus aids biological activity which in turn tends to push the phosphorus equilibrium in the direction of the organic end, the action becomes mutually helpful to both the biological activity and also to the increase of more quickly available phosphorus. This is especially true in soils where most of the phosphorus is in the more slowly available forms, as is often true in Hawaiian soils, especially in the red or yellow soils. In these soils biological activity and the maintenance of an active biological balance becomes doubly important. Because of the nature of the cropping system in the cane lands of Hawaii, it is hard to introduce organic matter to maintain this balance and as a result it has been largely neglected. However, the use of waste molasses for this purpose is quite possible and has been employed on some plantations in a very practical way and with little expense. This seems to be a rather simple way to dispose of the waste molasses and at the same time the sugar planter is able to maintain the biological activity in his soil at a higher level. The molasses also furnishes considerable available potash.

SUMMARY

In the presence of available energy material, the biological activity in Hawaiian laterites is greatly stimulated by the presence of available phosphorus, when measured by the assimilation of nitrate nitrogen by micro-organisms. In this combination with energy material, phosphorus helps prevent leaching of mineral nitrogen and also helps to build up a larger biological balance in the soil, which in turn increases the amount of phosphorus as well as nitrogen held in the organic form, thus increasing the availability of the phosphorus.

LITERATURE CITED

1. HECK, A. FLOYD. The relation of molasses to the micro-biological activity in soils. Hawaii Planters' Record, 34:301–306. 1930.
2. ————. Molasses as an aid in maintaining a biological balance in the soil. Hawaii Sugar Planters' Assoc., Progress of Work, Nov. 1930.
3. ————. The fertilizer value of molasses. Hawaii Sugar Planters' Assoc., Progress of Work, Jan. 1931.
4. ————. Phosphate fixation and penetration in soils. Soil Science, 37:343–355. 1934.

AGRONOMIC AFFAIRS

PRELIMINARY ANNOUNCEMENT OF THE PROGRAM OF THE SOILS SECTION OF THE SOCIETY

PROGRAM OF GENERAL SECTION

THURSDAY, DECEMBER 5

Morning: General Session of the Society.
Afternoon: Joint program with the American Soil Survey Association, 1:30 to 4:30, with brief summaries of the most important papers given before the various Commissions of the International Congress of Soil Science.

PROGRAM OF SOIL CHEMISTRY AND SOIL FERTILITY SUB-SECTION, DR. R. H. BRAY

CHEMISTRY

Thursday, 4:30– 6:00: Soil Testing.
Friday, 9:00–12:00: The Availability of Soil Potassium.

FERTILITY

Friday, 9:00–12:00: Soil Problems in Dry Land Farming, Dr. John S. Cole.
Friday, 1:30– 4:00: Papers Dealing with General Problems of Soil Fertility.

PROGRAM OF SOIL PHYSICS SUB-SECTION, DR. L. B. OLMSTEAD

Friday, 9:00–12:00: Physical Soil Constants.
Friday, 1:30– 4:00: Joint Session with Soil Chemistry; Physical and Chemical Studies of Soil Colloids.

PROGRAM OF SOIL BACTERIOLOGY, DR. H. W. BATCHELOR

Friday: as announced in September number of JOURNAL.

Wednesday afternoon there will be a program dealing with land utilization, under the direction of Dr. Morgan and Dr. Hutton, representing committees of the Soil Survey Association, and Dr. Bray, representing the Soils Section of the American Society of Agronomy.

JOURNAL
OF THE
American Society of Agronomy

VOL. 27 NOVEMBER, 1935 NO. 11

THE PLACE OF NITROGEN FERTILIZERS IN A PASTURE FERTILIZATION PROGRAM[1]

D. R. DODD[2]

A review of the literature on the use of nitrogen fertilizers on pasture land would be so extensive that this discussion is being confined to Ohio conditions and Ohio experiments. The splendid and well-known works of Vinall (1)[3], Fink, *et al.* (2), Brown (3), and many others are therefore omitted from discussion. Also, for the sake of brevity, detailed descriptions of the Ohio experiments referred to are being omitted.

In recent years it has become rather generally recognized that the margin of profit in most phases of livestock production is dependent upon the extent to which good pasture is utilized in its production. There are probably no other means of so greatly reducing the cost of production of livestock and livestock products as through improvement in the production and grazing of farm pastures. We are here considering the place of nitrogen fertilizers in such a pasture improvement program. In this respect we are concerned with the following questions:

1. When do nitrogen fertilizers give increased growth?
2. How much increased growth do they give?
3. What is the analysis of this increase?
4. Does it pay for the cost of production?
5. What is the place of nitrogen fertilizer in a well-balanced program?

EXPERIMENT 1

In 1928 there was begun at Columbus (4) a study of the effect of nitrogen fertilizers on Kentucky bluegrass sod. This involved, among other things, different rates of application. The area was of rather high productivity at the beginning of the experiment, consequently increases were not so great as in some other experiments, being only 2,195 pounds of dry matter and 631 pounds of protein where 200

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[1] Contribution from the Department of Agronomy, Ohio State University, Columbus, Ohio, and the Ohio Agricultural Experiment Station, Wooster, Ohio. Received for publication July 11, 1935.

[2] Extension Agronomist, Ohio State University; and Associate Agronomist, Ohio Agricultural Experiment Station.

[3] Reference by number is to "Literature Cited", p. 863.

pounds of the element nitrogen had been applied. At all times throughout the season and at all rates of application the production was greater on the nitrogen areas than on the check areas.

Outstanding features of this experiment, however, were the continued response in both dry matter and percentage of protein for successive additions of nitrogen up to the 200 pounds. In 1929, for example, the increase in pounds of protein resulting from the second 100 pounds of nitrogen was greater than from the first 100 pounds. The additional dry matter and protein might be expressed as 2,195 pounds of a 28.7 dairy feed. The dairy feed would cost much more than a nitrogen fertilizer carrying 200 pounds of nitrogen.

Under conditions of this experiment, if buying barn feed had been the alternative to the use of nitrogen even up to the rate of 1,000 pounds of a 20% carrier per acre, the latter would have been the more economical procedure. The actual average yields of the check plats were 1,932 pounds of dry matter and 310 pounds of protein in 1928 and 3,093 pounds of dry matter and 618 pounds of protein in 1929. The increases over these checks obtained from different rates of application of nitrogen are given in Table 1.

TABLE 1.—*Increased production resulting from various amounts of nitrogen per acre used as top dressing on bluegrass sod, Columbus, Ohio.**

Pounds of nitrogen	Dry matter, lbs. per acre	Protein, lbs. per acre	Protein of dry matter %	Nitrogen recovery %
		1928 results		
50..........	602	104	17.3	33.3
100..........	1,178	234	19.8	37.4
200..........	2,173	482	22.2	38.6
		1929 results		
50..........	958	184	19.2	58.9
100..........	1,328	314	23.6	50.2
200..........	2,195	631	28.7	50.4

*Nitrogen applied in two applications, March 15 and June 15.

EXPERIMENT 2

In 1929, another experiment in which nitrogen fertilizer was applied to a Kentucky bluegrass sod at 40-day intervals was started near Dayton (5). The main areas were grazed, but check areas were reserved for mechanical harvests. After 2 years at the original location it became necessary in 1931 to transfer the experiment to another location near Springfield.

The sod at the beginning of the experiment in both locations was what farmers would describe as very good. The period covered by this experiment was not favorable for large returns from nitrogen and the yields, as indicated by the special harvests, were low; but again, as in experiment 1, production of the treated areas remained above the checks throughout the season and represented a more economical source of feed than the commercial market.

In this experiment, however, the pasture was utilized by beef animals and records were kept of the gains produced. A summarization of these results for the 3 years of the experiment is given in Table 2.

TABLE 2.—*Production per acre of dry matter, protein, and beef; relationship of gains in beef to dry matter consumed; and fertilizer cost of production resulting from topdressings of nitrogen on bluegrass pasture near Dayton and Springfield, Ohio.**

	1929		1930		1931	
	With nitrogen	Without nitrogen	With nitrogen	Without nitrogen	With nitrogen	Without nitrogen
Dry matter, lbs.	2,948	2,048	2,131	1,315	5,501	4,827
Protein, lbs.	458	275	396	192	878	756
Beef, lbs.	177	98	260	103	297	200
Grass, in terms of dry matter, consumed per lb. of beef produced	16.6	20.9	8.2	12.7	18.6	24.1
Fertilizer cost per 100 lbs. of beef with N at 10c per lb.	$8.48		$2.87		$4.64	

*Nitrogen used: 67.5 lbs. in 1929; 45 lbs. in 1930 and 1931. Applied in lots of 15 lbs. each at 40-day intervals, beginning April 14, 1929, April 1, 1930, and April 9, 1931. Last treatment in 1929 at half rate.

Cattle: Angus steers in 1929, cows and heifers in 1930, mixed steers in 1931.

EXPERIMENT 3

A third experiment was begun in 1929 and continued to 1933 in which similar tests were made at the substations in Belmont, Trumbull, and Hamilton counties. Here, as at Dayton and Springfield, nitrogen was applied at 40-day intervals, the quantity per application being 15 pounds. No grazing data were obtained but check areas were harvested 40 days after treatment throughout the season. The locations and seasons were more favorable to nitrogen response and yields were much greater than in experiments 1 and 2.

The summarization for the three stations for the 4 years is contained in Table 3. Of particular interest was the consistent and definite manner in which the plats receiving nitrogen April 1 and the corresponding checks fell below those receiving their first nitrogen treatment later and their corresponding checks. The difference was probably due to the earlier cutting of the first plats. The harvests were made by a sickle and were rather close. This illustrates how a possible gain from nitrogen fertilizer may be offset by improper or untimely grazing.

EXPERIMENT 4

The next experiment with which we are concerned was started in 1931 on 43 farms in southeastern Ohio (6). In these tests, nitrogen was applied at two rates, 25 and 50 pounds, and in each case all in a single application between March 25 and April 25. Data were kept on changes in vegetative cover and fertilizer response. In Table 4 is

TABLE 3.—*Average yield and increase per acre of dry matter and protein and percentage of nitrogen recovered from 60 pounds of nitrogen applied to bluegrass pasture in four 15-pound applications at 40-day intervals, beginning about April 1 for plat 1, April 10 for plat 2, April 20 for plat 3, and April 30 for plat 4, Belmont, Trumbull, and Hamilton farms, 1929–33.**

Approximate date of first application	Yield, pounds		Increase, pounds		Nitrogen recovered %
	Dry matter	Protein	Dry matter	Protein	
April 1, check	1,974	275	—	—	—
April 1	3,349	536	1,375	261	69.7
April 10, check	1,828	259	—	—	—
April 10	4,226	707	2,398	448	102.7
April 20, check	2,261	301	—	—	—
April 20	4,767	809	2,506	508	135.3
April 30, check	2,720	345	—	—	—
April 30	5,247	874	2,527	529	141.0

*All plats received a basic treatment of superphosphate or 0-14-6.

given the summary of changes in vegetative cover, the complete fertilizer plat being the one receiving 50 pounds of nitrogen.

TABLE 4.—*Average composition of soil cover and percentage of bare ground in 1933 on plats in 44 pasture tests begun in 1931 in southeastern Ohio.*

Fertilizer treatment	Percentage of various types of vegetation and bare ground in soil cover				
	All clovers	Tame grass	Wild grass	Weeds	Bare ground
None	11	30	9	20	30
Phosphate	22	43	5	15	15
Phosphate and potash	25	43	5	13	14
Complete fertilizer	20	62	3	10	5

In Table 5 are presented the increases in dry matter for the years 1931, 1932, 1933, and 1934 for 25 and 50 pounds of nitrogen, respectively, over the phosphate-potash plat.

The nitrogen in this experiment, as in the others, produced feed at a much lower cost than the current commercial price for equivalent feeds. The second increment of nitrogen was also as effective as the first.

By means of factors determined from consideration of feeding standards, grazing experiments, and herbage composition and analysis, an attempt was made to express the gains made from various treatments in terms of beef and milk production. The results of these calculations indicated that phosphate fertilizer had greatly reduced the pasture cost per 100 pounds of possible milk and beef production and that nitrogen, in addition to phosphorus, had greatly increased the possible production of milk and beef but had not further lowered the cost per unit. The livestock very generally showed a preference for the grass of the nitrogen-treated areas. This was true also in other grazing experiments referred to.

TABLE 5.—*Response in increased yield of dry matter per acre resulting from nitrogen topdressing of bluegrass pasture.*

Pounds nitrogen applied	Increase of dry matter over phosphate-potash plat				
	1931 (43 tests)	1932 (36 tests)	1933 (34 tests)	1934 (30 tests)	Average
25	955	576	1,085	838	863
50	2,057	1,335	2,037	1,060	1,622

Where areas were permitted to make excessive growth and were then cut off close with a sickle in early June in hot dry weather, much damage to the stand and yield during the balance of the season resulted.

A further study of the data in this experiment indicated rather conclusively that nitrogen was relatively much more effective in non-white clover years and on pastures where white clover had not been prevalent. Moisture and height of grazing were apparently the chief factors in determining the white clover content of pastures which had sufficient lime and phosphate.

EXPERIMENT 5

Experiment 5 was started at Columbus in the spring of 1934. Nitrogen was applied to a good Kentucky bluegrass sod at the rates and in the amounts indicated in Table 6 and gave responses by months as shown in the same table. Due to a very unfavorable growing season, all yields were low and the results are for a single year. They are given in detail since they represent the same tendencies pointed out in a general way in previous experiments.

EXPERIMENT 6

A sixth experiment was started at the Schaaf Dairy Farm near Columbus in 1929 (7, 8). This was a rotational grazing experiment involving 60 to 70 cows and 30 acres of good Kentucky bluegrass divided into six paddocks. In addition to a basic treatment of 500 pounds of 20% superphosphate and 120 pounds of muriate of potash per acre, applied in the spring of 1929, four applications of sulfate of ammonia, totaling 500 pounds were made in 1929 and 1931. In 1930, a drouth year, only three applications totaling 400 pounds were made.

In addition to the complete fertilizer grazing areas, the experiment also included small areas with different fertilizer treatments for the purpose of determining by artificial harvests the relative production

TABLE 6.—*Yield of dry matter and protein in pounds per acre resulting from nitrogen topdressing bluegrass pasture, 1934.*

Treatment	April		May		June		July		August		September		Total	
	Dry matter	Protein	Dry matter	Protein	Dry matter	Protein	Dry matter	Protein	Dry matter	Protein	Dry matter	Protein	Dry matter	Protein
No nitrogen	276	50	388	56	84	13	69	17	393	71	64	10	1,274	217
20.5 lbs. N, Apr. 5	361	81	608	94	99	15	83	16	453	85	70	12	1,674	303
41.0 lbs. N, Apr. 5	360	93	748	136	119	19	93	18	486	82	92	15	1,898	363
61.5 lbs. N, Apr. 5	433	116	867	162	121	20	98	20	524	107	107	19	2,150	444
20.5 lbs. N, Apr. 5, June 1, and Sept. 1	304	69	592	94	158	25	136	30	540	105	204	44	1,934	367

TABLE 7.—*Average yields and increases per acre of dry matter and protein and percentage of protein, Schaaf dairy pasture.*

Treatment	1929			1930			1931		
	Pounds dry matter	Pounds protein	Protein %	Pounds dry matter	Pounds protein	Protein %	Pounds dry matter	Pounds protein	Protein %
None	2,241	358.7	16.0	541	102.5	18.9	2,037	380.6	18.7
PK	2,749	476.5	17.3	785	165.0	21.0	2,631	471.7	17.9
NPK	4,328	845.9	19.5	1,479	352.0	23.8	4,355	936.7	21.5
				Increases					
PK over Ck	508	117.8	23.1	244	62.5	25.6	594	91.1	15.4
NPK over Ck	2,087	487.2	23.3	938	249.5	26.6	2,318	556.1	24.0
NPK over PK	1,579	369.4	23.4	694	187.0	26.9	1,724	465.0	27.0

of phosphate and potash in combination but without the nitrogen. The results obtained from these small areas are summarized in Table 7.

The production for the NPK plats was always above the PK and check plats throughout the season. The margin by which the complete fertilizer plats excelled, however, was greater in the spring and fall than in mid-summer. The PK plats showed the same tendency to run ahead of the check plats in production in midsummer and fall as well as in the early part of the season. This was true in 11 out of 12 comparisons in July and again in August. The season was so abnormally dry in 1930 that yields for that year, as indicated in Table 7, are not in line with the other two years and might be ignored.

Assuming that the mineral fertilizers would last over a period of 4 years, $2.31 worth of superphosphate and potash produced 508 pounds of a 23.1% protein feed in 1929 and 594 pounds of a 15.4% protein feed in 1931. In comparison to this $7.50 worth of nitrogen fertilizer produced 1,579 pounds of a 23.4% protein feed in 1929 and 1,724 pounds of a 27.0% protein feed in 1931. This again is a much smaller amount of money than would be required to purchase a more or less comparable feed on the general market. There is, of course, the possibility that such feed might be produced by some other means on the farm for less than the general market price.

Results from grazing.—The nitrogen fertilizer more than doubled the carrying capacity of the pasture. While the estimated carrying capacity at the beginning of the test was 0.73 cow per acre for 155 days, it was actually 1.82 cows per acre for 173 days in 1929, 0.90 cow per acre for 184 days in 1930, and 1.82 cows per acre for 172 days in 1931. Records were kept of feed consumed and milk produced, but since the cows were at all times on manger feed, it would hardly be fair to attribute all gain above feed cost to pasture. It happened, however, that June and July of 1930 produced no pasture. From feeding costs during these 2 months and from costs at the beginning and end of the pasture season, it was possible to determine the feed cost per cow without pasture. This has been taken advantage of in calculating the value, in terms of manger feed replaced, of the pasture produced by the complete fetilizer treatment. This total value has been apportioned to the credit of nitrogen, phosphate and potash, and normal response without treatment in proportion to the yields of dry matter resulting from these three factors as reported in Table 7. The results of this apportionment are given in Table 8.

It is obvious from the data of Table 6 that the increased production resulting from fertilization was of higher analysis and doubtless of greater feed value than that of the natural production without fertilizer. This being the case, the actual value of the grazed herbage resulting from fertilization should doubtless be slightly greater and that resulting from natural productivity slightly less than indicated in Table 8.

The prices assigned to the various feeds replaced are probably as low as those for which most farmers would be willing to produce these products. Since the fertilizers still show a satisfactory return, it would appear that at least on dairy farms where high-quality pasture can be utilized, the use of nitrogen fertilizer on pasture is thoroughly justified.

TABLE 8.—*Acre value of pasture herbage produced, cost of fertilizers (applied), and net difference, calculated on basis of manger feed replaced.**

Items	Dollars per acre		
	1929	1930	1931
Value of herbage on complete treatment area	$56.35	$20.87	$53.09
Value of herbage due to natural production	29.87	6.51	24.42
Value of herbage due to nitrogen fertilizer	20.05	10.62	21.33
Value of herbage due to phosphate and potash	6.43	3.74	7.34
Cost of nitrogen (applied)	8.50	6.75	8.50
Cost of phosphate and potash (applied)	3.17	3.17	3.17
Return from nitrogen above cost	11.55	3.87	12.83
Return from phosphate and potash above cost	3.26	0.57	4.17

*Feed prices assumed for these calculations: Western alfalfa hay $15.00 per ton; local alfalfa hay $12.00 per ton; clover, soybean and mixed hay $10.00 per ton; timothy hay $8.00 per ton; silage $4.00 per ton; grain ration $25.00 per ton.

SUMMARY OF EXPERIMENTS

Six Ohio experiments involving the use of nitrogen fertilizers on Kentucky bluegrass pasture have been briefly presented. The data indicate that:

1. Nitrogen-fertilized grass is more palatable and is grazed more closely than adjoining areas of grass which have had no nitrogen.
2. Early clipping, intended to approximate early close grazing, greatly reduced the effectiveness of nitrogen in increasing grass yield.
3. Close clipping in June in hot dry seasons, intended to approximate close grazing of areas earlier, permitted excessive growth, greatly reduced the stand and the yield later in the season and consequently the possible return from fertilization.
4. Nitrogen fertilizer applied early in the spring increased the production not only in the early spring but throughout the season, as indicated by regular and uniform mechanical harvests. With different soil conditions or with limited mineral nutrients this might have been different. The increased production during July and August, however, was so little that this could not be considered as a means of meeting the mid-summer pasture shortage.
5. Making a second or third application of nitrogen later in the season materially increased the fall growth.
6. The exact time of response in extra growth resulting from nitrogen treatments appeared to be dependent upon moisture and temperature conditions. Good growth was obtained in both July and August under favorable moisture conditions.
7. Nitrogen was relatively less effective on sods carrying a high white clover content and in years of high white clover content. The percentage of white clover appeared to fluctuate from year to year depending largely upon moisture and temperature conditions.
8. Nitrogen applied to sods already well supplied with lime and phosphate produced feed at a much lower cost than feeds of similar analysis could be purchased on the market.

9. The law of diminishing returns from increased applications of nitrogen fertilizer appeared to operate at a much higher level than had been previously generally assumed. It appears that the rate of application of such fertilizer up to at least 60 pounds of nitrogen per acre should, in general practice, be determined largely by the amount of pasture required.

THE OHIO PASTURE PROGRAM WHERE PERMANENT PASTURE IS AVAILABLE

In Ohio good response has been obtained from lime, phosphate, and manure on the generally depleted pasture areas. These materials cost less than nitrogen, they need not be applied so frequently, and the first two appear to be essential to satisfactory returns from nitrogen. The Ohio pasture improvement program, therefore, begins with the use of these materials. Once they have been applied to the general pasture area, there may yet be a shortage of pasture in early spring and July and August or in some instances even in the main grazing season.

For this early spring period it is recommended that an area of good bluegrass sod be set aside. In addition to periodic applications of lime, if needed, phosphate, and possibly manure, this area should receive annually early in the spring a liberal application of nitrogen fertilizer. Since livestock will show a preference for this nitrogen area and are likely to over-graze it later, it must be fenced separately from the main pasture area and protected from over-grazing. Little or no grazing should be permitted after September 1. In event a Kentucky bluegrass sod is not available, timothy, orchard grass, or tall meadow oat grass may be used, or a special crop such as rye may be substituted.

For the July-August period Sudan grass, alfalfa, or alfalfa mixtures are recommended.

Should this leave a shortage in the main grazing season, nitrogen may be applied to the main pasture area further to boost growth at that time. This would be especially desirable in years of a low white clover content, which may be determined by observation of weather condition and clover content the previous fall.

This program is presented in graphic form in Fig. 1.

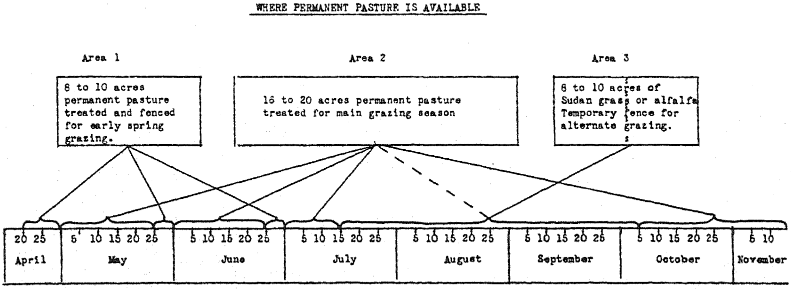
WHERE PERMANENT PASTURE IS AVAILABLE
Area 1
Area 2
Area 3
8 to 10 acres permanent pasture treated and fenced for early spring grazing.
16 to 20 acres permanent pasture treated for main grazing season
8 to 10 acres of Sudan grass or alfalfa Temporary fence for alternate grazing.
20 25
April
5 10 15 20 25
May
5 10 15 20 25
June
5 10 15 20 25
July
5 10 15 20 25
August
5 10 15 20 25
September
5 10 15 20 25
October
5 10
November

FIG. 1.—Suggested plan for pasture for 24 cows for the entire grazing season.

There is probably no other means of so greatly reducing the cost of livestock and milk production and increasing the net farm income on the average Ohio farm as by giving more attention to the pasture program. It is therefore given a major consideration by the college and experiment station. It is recognized, however, that satisfactory returns will result only when fertilization is accompanied by proper management and the extra production is utilized by a good quality of livestock.

LITERATURE CITED

1. VINALL, H. N., and HEIN, M. A. Seasonal production of grasses and legumes at Beltsville, Maryland, in 1931. Jour. Amer. Soc. Agron., 25:588–594. 1933.
2. FINK, D. S., MORTIMER, G. B., and TRUOG, E. Three years' results with intensely managed pastures. Jour. Amer. Soc. Agron., 25:441–453. 1933.
3. BROWN, B. A. Pasture investigations. Storrs Agr. Exp. Sta. Bul. 190. 1933.
4. MCCLURE, GEORGE M. Nitrogen on pasture grasses. Ohio Agr. Exp. Sta. 48th Ann. Rpt.: 47–48. 1929.
5. GERLAUGH, PAUL, SALTER, R. M., and WELTON, F. A. Nitrogen topdressing of bluegrass grazed by beef cattle, II. Ohio Agr. Exp. Sta. 49th Ann. Rpt.: 153–155. 1931.
6 DODD, D. R. Fertilizer experiments on farm pastures. Ohio Agr. Exp. Sta. 50th Ann. Rpt.: 36–37. 1932.
7. SALTER, R. M., and YODER, R. E. The intensive management of permanent pastures in dairy farming. Ohio Agr. Exp. Sta. Bi-monthly Bul. No. 152: 155–163. 1931.
8. YODER, R. E. A study of an intensive system of fertilization and management of bluegrass pasture in central Ohio. Unpublished doctorate dissertation, Ohio State University. 1932.

THE DETERMINATION OF THE FORMS OF INORGANIC PHOSPHORUS IN SOILS[1]

R. ANDERSON FISHER AND R. P. THOMAS[2]

SOIL phosphates occur in such a fine state of division and in such small proportions in the soil mass that no satisfactory methods have existed for the estimation of the different forms present. Such a method, however, would be very desirable and probably will form a basis of the eventual laboratory tests of phosphate availability. In the investigation here reported, a rapid method has been developed for estimating the inorganic soil phosphorus contained in four groups of materials based upon relative rates of solution in buffered acid extractants. The four groups are as follows: (A) Amorphous and finely divided crystalline phosphates of calcium, magnesium, and manganese; (B) amorphous phosphates of aluminum and iron; (C) phosphates adsorbed upon hydrous oxides and those present in the form of apatite; and (D) by difference, phosphates present in crystalline phosphates of aluminum and iron.

By placing the proper values upon the phosphorus contained in each group it was found that analyses by this method placed 22 Maryland soils, representing 3 provinces, 7 series, and 12 types, in practically the identical order of phosphorus requirements as that disclosed by pot tests.

METHODS OF PROCEDURE

Preliminary studies upon rates of solution indicated that extractions at two pH values would be necessary in order to distinguish phosphorus present in amorphous and finely divided crystalline phosphates from adsorbed phosphorus and phosphorus present in apatite. Two extractants with pH values of 2 and 5 were adopted for this purpose. The pH 2 solution consists of a 0.002 N sulfuric acid and 0.3% of potassium acid sulfate. The hydrogen-ion concentration of this solution ranged between pH 1.95 and 1.97. This solution was first used in 1932 (Maryland Experiment Station unpublished data) and since has been used by other workers (1)[3]. Experiments have shown that this extraction solution, when used in the usual proportion, changed only 0.35 pH with a soil containing 10% calcium oxide. The second extractant was a buffered solution of acetic acid containing 3.6 ml of concentrated acetic acid per liter and 19.04 grams of sodium acetate. The hydrogen-ion concentration of different lots of solutions made up in this manner had a range in pH value of 4.98 to 5.02. When used to extract soil containing 20% of calcium oxide, the reaction of this extractant changed only 0.30 pH. These two extracting solutions are designated by their respective approximate pH values.

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[2] Graduate Assistant, now soil surveyor with headquarters at Pullman, Washington, and Associate Professor, respectively.

[3] Figures in parenthesis refer to "Literature Cited", p. 873.

Solubility studies.—As pure phosphorus compounds are not easily separated from soils for study purposes, pure amorphous compounds (freshly prepared and not dehydrated) and crystalline phosphate minerals were used to obtain data upon their rates of solution at the two pH values. Since solubility invariably depends upon the amount of surface exposed, an effort was made to control the surface exposed by passing all materials studied through a 100-mesh sieve and rejecting that part passing a 200-mesh sieve. Amounts of materials were used which gave similar phosphorus concentration in the extraction mixture as was obtained in the extraction of soils low in phosphorus.

Extraction method procedure.—On the basis of the solubility data obtained, the following procedure was formulated for extracting soils to determine the forms of phosphorus:

Weigh out three 2-gram samples of each soil and place in separate 750-ml Erlenmeyer flasks. The soil should be air dry and screened through a 20-mesh screen. Add to two of each set of three flasks, 400 ml each of the pH 5 extractant. An equal volume of the pH 2 solution is added to the third flask of each soil. In order that each soil sample may be placed in contact with extracting solution at the same time, it is desirable to have the solutions measured out ready to add to the respective flasks. After noting the time, stopper and place in an end-over-end shaker. While the flasks are shaking prepare for filtering through either 12.5 cm No. 40 or 11 cm No. 41 Whatman filter paper, or filter papers of equal quality. One-half hour after the extractants were added remove one of the pH 5 extraction flasks for each soil and filter, catching the filtrate in a 250- to 300-ml Erlenmeyer flask. The first 25 to 30 ml should be discarded. Remove funnels from the receiving flasks three quarters of an hour after extractants were added, or 15 minutes after removing from shaker. Only the filtrate which has run through the filter in this time is used for the subsequent phosphorus analysis. Suitable aliquots of the filtrates are taken[4] for the regular colorimetric phosphorus determinations (2). Remove the remainder of the pH 5 flasks at the expiration of 2 hours and filter, removing funnels at 2¼ hours. Determine the phosphorus in these filtrates as before. Terminate the shaking of the pH 2 extractions at 2¾ quarters hours and filter, removing funnels at 3 hours. Phosphorus is determined on the filtered extract in the same manner.

The results obtained by this procedure on 22 Maryland soils and various phosphate minerals and compounds are reported in Tables 1, 2, and 3.

Leaching studies.—Soils and pure phosphate materials were leached with the pH 5 and 2 solutions to ascertain the fractions of "B" and "C" group phosphorus removed by the previously described extraction method. An improved apparatus set up after Russel (4) was employed. The dropping tubes were made of capillary tubing to allow of greater precision in the control of the rate of flow. They were adjusted to drop 200 ml of extractant every 4 hours. Readings were made upon each 200 ml separately. The phosphorus obtained in this manner is reported in Tables 4, 5, 6, and 7.

Crop indexes on soils studied.—Tomatoes and millet were grown in the greenhouse upon the 22 Maryland soils which had been placed in half-gallon glazed pots. Since none of these soils had been recently cultivated or had received fertilizer treatment during the past 10 years, they should not contain any phosphate fertilizer residues. Nitrogen and potassium were added in order to eliminate them as possible growth-limiting factors. Part of each soil received phosphorus.

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[4] The ammonium molybdate sulfuric acid reagent for use at pH 5 should contain 370 cc of concentrated sulfuric acid per liter instead of the usual 280 cc.

The responses to a 1,000 pounds per acre application of superphosphate are expressed as percentage increase for the tomato crop in Table 8. The soils are arranged in descending order of crop yield in this table. This arrangement also places them in the order of their increase in soluble or nutritional phosphorus content. A similar response was obtained for the millet. Figs. 1 and 2 show the growth of millet obtained with and without phosphorus treatment for soils 1, 3, and 13.

TABLE 1.—*The phosphorus obtained by the proposed extraction method from 22 Maryland soils.*

No.	Soil type studied	H ion concentration pH	Phosphorus extracted		
			By pH5 solution		By pH 2 solution in 3 hr., p.p.m.
			In ¾ hr., p.p.m.	In 2¼ hr., p.p.m.	
1	Portsmouth loam	4.2	8.00	8.00	125.0
2	Sassafras loamy sand	4.5	1.00	1.00	6.0
3	Elkton loam	5.2	4.75	6.25	27.5
4	Sassafras loam	6.1	3.25	5.25	22.0
5	Sassafras silt loam	5.7	2.25	3.00	23.0
6	Sassafras silt loam	6.2	2.00	4.00	28.5
7	Sassafras silt loam	5.3	2.25	2.87	23.0
8	Keyport silt loam	4.7	5.50	9.00	25.0
9	Elkton silt loam	4.5	2.50	3.12	14.5
10	Keyport loam	6.0	3.50	7.00	45.5
11	Sassafras sand	5.5	7.00	14.00	190.0
12	Elkton silt loam	4.7	2.87	3.12	23.0
13	Manor loam	5.0	2.00	2.00	18.0
14	Hagerstown silt loam	6.0	0.50	1.00	6.5
15	Manor loam	6.0	2.25	2.25	12.0
16	Manor loam	5.0	2.00	2.00	28.0
17	Frankstown silt loam	5.5	1.25	1.75	14.0
18	Frankstown silt loam	8.0	4.00	4.00	40.0
19	Hagerstown silt loam	7.0	3.25	3.31	18.5
20	Frankstown silt loam	8.5	6.75	7.50	37.0
21	Hagerstown silt loam	6.5	0.50	1.0	7.0
22	Sassafras silt loam	6.3	6.75	8.0	34.0

DISCUSSION

Solubility studies revealed the fact that apatite, which leading soil authors assume to be the most abundant form of soil phosphate, is practically insoluble at pH 5. Further, as the pH value of the extraction solution was decreased from 5 to 4 then 3, the solubility of apatite increased. It was completely soluble at pH 2. Again the phosphorus present in the amorphous and finely divided crystalline phosphates of calcium, magnesium, and manganese, and in the amorphous phosphates of iron and aluminum, was in each case appreciably dissolved at pH 5 and very largely dissolved at pH 2. This is substantiated by the data given in Tables 2 and 3. The pH 5 extractant could therefore be used to differentiate between the phosphorus present in these simple compounds and that present in apatite or compounds of similar solubility. It was found also that in three-quarters of an hour the pH 5 extractant removed practically all the phosphorus from tricalcium phosphate, from tertiary magnesium phosphate, and from manganese phosphate. One to 2% of the phosphorus present as amorphous phosphates of iron and aluminum were obtained within this time. Tripling the time of extraction, or 2¼ hours, removed double the amount of phosphorus from the amorphous phosphates of aluminum and iron. The pH 5 extractant has made it possible to differentiate between the two following groups of simple phosphates: (A) Amorphous and finely divided crystalline phosphates of calcium, magnesium, and manganese; and (B) amorphous phosphates of iron and aluminum.

TABLE 2.—*The parts per million of phosphorus extracted from phosphorus minerals by pH 5 and pH 2 solutions.*

The source and treatment of the phosphorus materials studied	Amount per 400 ml of extractant, mg.	The phosphorus extracted from materials			
		By pH 5 solution			By pH 2 solution in 3 hr., p.p.m.
		In ¾ hr., p.p.m.	In 2¼ hr., p.p.m.	In 3 hr., p.p.m.	
Apatite:					
(a) U. S. D. A. No. B 15...	5.5	1.3	—	1.5	360.0
(b) U. S. D. A. H_2O leached..................	5.5	—	—	—	—
(c) Quebec.............	5.5	1.5	—	—	400.0
(d) Quebec H_2O leached..	5.5	1.0	—	—	—
(e) Russia.............	5.5	0.5	—	—	365.0
(f) Russia H_2O leached...	5.5	—	—	—	—
(g) Chlorapatite.........	5.5	2.0	—	2.0	—
Vivianite:					
(a) Penn................	5.5	8.0	—	—	285.0
(b) Penn H_2O leached.....	5.5	0.7	—	—	—
(c) Penn H_2O leached.....	50.0	—	13.0	19.5	—
(d) Australia...........	5.5	—	15.5	—	—
Dufrenite:					
(a) Virginia............	5.5	—	—	—	—
(b) Virginia............	20.0	—	—	—	5.3
(c) England............	5.5	0.5	—	—	7.0
Cacoxonite...............	5.5	—	—	—	5.5
Strengite................	5.5	—	—	—	1.5
Variscite................	5.5	—	1.8	—	10.5
Wavellite:					
(a) Arkansas...........	5.5	0.2	—	0.2	5.0
(b) Columbia...........	5.5	0.7	—	—	—
Fischerite...............	5.5	2.0	—	—	—
Titanium Phosphate.......	5.5	17.0	—	—	—
Manganese Phosphate......	5.5	360.0	—	—	—
Rock Phosphate:					
(a) Florida.............	5.5	23.0	—	—	—
(b) Curacoa............	5.5	80.0	—	—	—
(c) Wyoming...........	5.5	5.0	—	—	—

TABLE 3.—*The phosphorus removed from phosphorus materials during different periods of contact with the pH 5 solution.*

Weight of 400 ml of extractant, mg	Time of contact with solution and phosphorus removed, p.p.m.			
	¾ hr.	1½ hr.	2¼ hr.	3 hr.
Aluminum Phosphate				
5.1	9.0	19.0	—	—
5.3	11.0	—	—	24.0
10.0	32.5	—	51.5	—
	(47.5)*	—	(126.0)*	—
20.4	—	80.0	—	—
50.0	31.0	—	127.0	—
100.0	—	—	390.0	—
Ferric Phosphate				
5.5	4.0	—	—	8.0
10.0	10.0	—	13.5	—
	(10.5)*	—	(14.0)*	—
23.2	—	30.0	—	—
50.0	25.0	—	38.00	35.0
100.0	—	—	114.0	—
Tricalcium Phosphate				
2.0	—	155.0	—	—
8.0	—	730.0	—	—
4.9	400.0	—	—	—
Tertiary Magnesium Phosphate				
4.3	260.0	—	—	—

*Data on 200-meshed material.

In order to use the pH 5 extractant for this purpose it has been necessary to determine the proportion of the "B" group phosphorus which the pH 5 extractant actually removed from soils by the ¾ hour and the 2¼ hours of extraction. This is on account of the unknown fineness of these "B" group materials as they occur in soils. The proportion of each of these forms of phosphorus removed by the two different times of extraction or the numerical value to give to each period of extraction was calculated from the continuous leaching studies. The data in Table 1 show that the phosphorus extracted by the pH 5 solution in the 2¼ hours period is double the amount obtained in ¾ hour in the case of soils Nos. 6, 10, 11, 14, and 21. This is what would be expected on the basis of the solubility studies if there were no "A" group phosphorus present in these soils.

It might appear from the solubility data, as given in Table 2, that some of the definite crystalline aluminum and iron phosphates were obtained along with the amorphous aluminum and iron phosphates. An example of this would be vivianite. This should be expected to a certain extent because the change from the amorphous to pronounced crystalline structures is probably gradual. The large amount of amorphous phosphorus found in the Sassafras sand (No. 11 as reported in Table 9) might be partly attributed to such an explanation. The data in Table 9 indicate, also, that the group C phosphorus

TABLE 4.—*Phosphorus removed from phosphorus materials and soils by separate 200 ml aliquots of the pH 5 solution every 4 hours.*

Consecutive leaching numbers	Phosphorus leached from different kinds and amounts of materials, p.p.m.							
	10 mg aluminum phosphate	10 mg ferric phosphate	10 mg titanium phosphate	10 gr Sassafras soil No. 6	10 gr Keyport soil No. 10	5 gr Sassafras soil No. 11	10 gr Elkton soil No. 12	10 gr Hagerstown soil No. 19
1	70.0	22.0	100.0	20.5	9.0	29.0	7.5	16.0
2	55.0	11.0	61.0	15.0	10.0	31.0	4.5	16.0
5	56.0	8.5	29.0	7.5	8.0	19.0	5.5	5.0
10	34.0	9.0	24.0	5.0	7.5	16.5	6.0	2.5
15	33.0	7.0	7.0	5.0	7.0	14.0	6.0	2.0
20	29.0	7.0	14.0	3.5	6.5	13.0	6.0	2.0
25	27.0	7.0	9.5	3.0	5.5	9.5	5.5	1.5
30	21.0	7.0	9.5	3.0	4.5	8.5	4.5	1.5
35	18.5	6.5	20.5	3.0	5.0	9.0	4.0	1.5
40	17.0	7.0	9.5	2.5	5.0	8.5	3.5	1.0
45	13.5	8.0	7.5	2.5	4.5	7.5	3.5	1.0
50	10.5	7.0	11.0	2.5	3.0	5.5	3.0	1.0
60	2.5	6.0	5.0	1.5	3.0	4.0	1.5	0.5
70	0.5	6.0	10.0	1.0	2.0	2.5	1.5	0.5
80	—	5.0	8.0	1.0	2.0	3.0	1.5	—
90	—	5.5	9.0	0.5	1.0	3.0	1.5	—
100	—	5.0	7.0	—	0.5	0.5	—	—
120	—	5.0	—	—	—	—	—	—

TABLE 5.—*The phosphorus removed from some Maryland soils by separate 200 ml aliquots of the pH 2 solution every 4 hours after a previous leaching with the pH 5 solution.*

Consecutive leachings	Phosphorus extracted from soils, p.p.m.				
	No. 6 Sassafras sandy loam	No. 10 Keyport loam	No. 11 Sassafras sand	No. 12 Elkton silt loam	No. 19 Hagerstown silt loam
1–4	31.0:36.0	64.0:62.0	95.0:90.0	30.0:30.0	20.0
5–8	17.5:16.3	41.0:40.0	8.5:12.0	5.0: 5.0	21.0
9–12	7.0: 7.5	24.5:24.5	5.0: 5.0	3.0: 3.5	16.5
13–16	5.0: 3.5	20.0:20.0	3.0: 3.0	2.0: 1.5	12.5
17–20	4.5: 5.0	12.5:11.5	1.75:1.25	1.75:1.25	10.0
21–24	——	9.0: 9.5	——	——	8.5
30–60	——	——	——	——	4.0

TABLE 6.—*The phosphorus extracted from three Maryland soils by continuous leaching with pH 2 solution in 200 ml portions every 4 hours.*

Soil used	Consecutive leachings	Average phosphorus content, p.p.m.	Soil used	Consecutive leachings	Average phosphorus content, p.p.m.
No. 19 Hagerstown silt loam	1	160.0	No. 12 Elkton silt loam	1–2	150.0
	2	56.0		3–6	12.5
	3	42.0		7–10	9.0
	4	30.0		11–14	1.5
	5	29.0			
	6	26.0	No. 10 Keyport loam	1–2	264.0
	7	24.0		3–6	98.0
	8	20.5		7–10	30.0
	9	19.5		11–14	14.0
	10–13	11.5		15–18	13.5
	14–17	9.5		19–22	12.0
	18–21	8.5		23–26	9.0
	22–25	8.0		27–30	5.5
	26–29	7.5			
	30–33	6.0			

TABLE 7.—*The total amount of phosphorus leached from pure phosphates and five Maryland soils by the pH 5 and pH 2 solutions.**

Phosphates and soils	Weight of sample leached, gram	Phosphorus obtained by continuous leaching, p.p.m.		
		With pH 5	With pH 2 after pH 5	With pH 2
Aluminum phosphate	0.010	1,393	——	——
Ferric phosphate	0.010	760	288	——
Titanium phosphate	0.010	1,294	572	——
Sassafras sandy loam No. 6	10.0	275	268	——
Keyport loam No. 10	10.0	393	676	1,250
Sassafras sand No. 11	5.0	754	452	——
Elkton silt loam No. 12	10.0	322	164	390
Hagerstown silt loam No. 19	10.0	138	392	590

*Summary of data given in Tables 3, 4, and 5.

or that absorbed on the hydrous oxides of aluminum and iron and that similar to apatite is relatively limited in the majority of the Maryland soils. This is in accord with the work of Robinson, *et al.* (3). It is reasonable to assume, therefore, that any phosphorus material

TABLE 8.—*The arrangement of the soils in the order of their phosphorus nutritional value and in the order of crop responses to phosphorus treatment.*

Nutritional phosphorus or that contained in groups A + 6/11 B plus			Soils arranged in order of		Increase in crop yield for phosphorus %
1/10 C, p.p.m.	1/40 C, p.p.m.	1/20 C, p.p.m.	Increase in nutritional phosphorus, No.	Decrease in crop response, No.	
2.0	1.3	1.5	2	13	—
5.0	1.8	2.6	13	2	3,000
4.0	2.75	3.3	15	15	2,500
3.4	3.1	3.3	14	14	2,400
3.4	3.2	3.4	21	21	2,400
7.2	3.3	4.8	16	16	1,000
6.6	3.0	5.2	19	19	910
5.8	4.25	5.5	17	17	800
8.9	6.43	5.8	7	7	800
6.0	5.10	5.9	12	20	600
7.8	5.92	6.1	9	18	430
9.6	6.90	7.7	5	12	380
12.0	5.80	8.0	18	5	300
15.8	11.33	12.7	20	9	280
15.3	14.7	13.6	6	6	130
15.9	13.0	13.8	3	1	124
15.25	13.69	14.0	4	3	122
16.8	13.6	15.1	22	22	60
33.0	23.0	20.0	1	4	36
23.2	23.0	23.0	8	8	36
25.9	22.2	23.4	10	10	20
74.0	50.0	58.0	11	11	—

more soluble than apatite will have been more completely removed from soils of any maturity. This assumption was substantiated by the results obtained on the Maryland soils. Although the solution data (Table 2) showed that the pH 2 extractant dissolved small amounts of the more insoluble crystalline aluminum and iron phosphates, it is felt that if the material soluble in water had been previously removed the pH 2 soluble phosphorus would have been reduced.

The rôle of absorbed phosphorus or the phosphorus which might be retained by the soil from application of fertilizer was investigated. Hydrous oxides of aluminum and iron which contained 4,000 p.p.m. of absorbed phosphorus were treated with the two extracting solutions. The pH 5 reagent removed none of this phosphorus in 2¼ hours, and the pH 2 solution extracted 2,600 p.p.m. of the phosphorus in 3 hours.

Leaching results, as reported in the condensed form in Tables 4, 5, 6 and 7, show a close relationship between the rate of solution of the phosphorus from the soils and from pure amorphous aluminum phosphates by the pH 5 extractant. This is believed to indicate the presence of similar aluminum phosphates in the soils. The large amount of phosphorus obtained by the first few of the pH 2 leachings, following the pH 5 extraction, as shown by the data in Table 5, was taken as indicating that absorbed phosphorus and apatite forms were first dissolved and then the more insoluble phosphates of aluminum and iron were being slowly brought into solution.

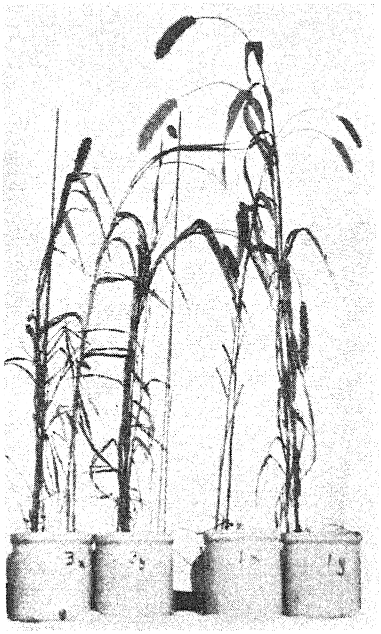

FIG. 1.—The growth of millet on soils 1 and 3. Y represents no phosphorus treatment and x 1,000 pounds of superphosphate per acre.

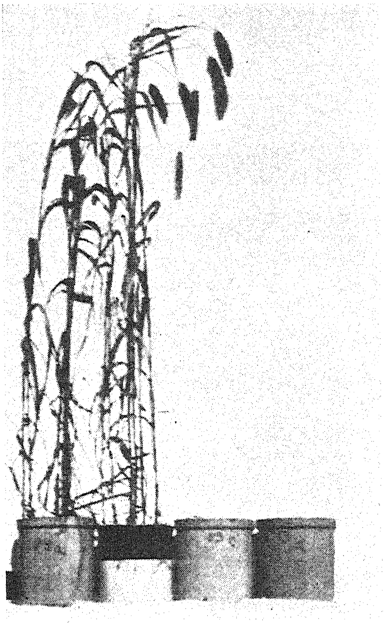

FIG. 2.—The growth of millet on soil 13. A and b received superphosphate at the rate of 1,000 pounds per acre and c and d no phosphorus.

SCHEME OF SEPARATION

The data obtained from the extracting and leaching studies are used for a proposed method of separating the available soil phosphates into three groups. The total phosphorus which can be extracted by leaching at pH 2 within reasonable time can be divided into three groups A, B, and C. The A group is comprised of amorphous and finely divided crystalline phosphates of calcium, magnesium, and manganese. The B group is composed of amorphous phosphates of iron and aluminum. The C group is composed of adsorbed phosphorus and of apatite. The following is a simple way of expressing these separations using the letters to signify the respective groups of materials:

1. pH 5 for ¾ hour gives $A + B/11$.
2. pH 5 for 2¼ hours gives $A + B/5.5$.
3. pH 2 for 3 hours gives $A + 6B/11 + C/20$.

These expressions make the estimation of the phosphorus present in each group very simple algebra after the three extractions have been carried on.

TABLE 9.—*The total content of easily soluble (group A), slightly soluble (group B), and less soluble (group C) forms of phosphorus in the 22 Maryland soils calculated from the extraction data and using the proposed algebraic formula.*

No.	Soil type	The phosphorus content by groups, p.p.m.		
		A	B	C
1	Portsmouth loam	8.00	—	234.0
2	Sassafras loamy sand	1.00	—	10.0
3	Elkton loam	4.25	16.5	28.5
6	Sassafras loam	1.25	22.0	17.5
5	Sassafras silt loam	1.50	8.3	34.0
6	Sassafras sandy loam	—	22.0	33.0
7	Sassafras silt loam	1.63	6.8	35.3
8	Keyport silt loam	—	38.5	4.0
9	Elkton silt loam	1.87	6.8	17.9
10	Keyport loam	—	38.5	49.0
11	Sassafras sand	—	77.0	216.0
12	Elkton silt loam	1.87	2.8	45.7
13	Manor loam	2.02	—	34.0
14	Hagerstown silt loam	—	5.5	7.0
15	Manor loam	2.25	—	19.5
16	Manor loam	2.00	—	52.0
17	Frankstown silt loam	0.75	5.5	20.5
18	Frankstown silt loam	4.00	—	72.0
19	Hagerstown silt loam	3.20	0.7	29.8
20	Frankstown silt loam	6.00	8.3	53.0
21	Hagerstown silt loam	—	5.5	8.0
22	Sassafras silt loam	5.50	13.8	42.0

NUTRITIONAL VALUES OF A, B, AND C GROUP PHOSPHORUS

In the pot tests on the Maryland soils and in the subsequent analyses by the above method, the significance of this method has been clearly demonstrated. Considering only the A and B group phosphorus in these soils, it was found that adding only 6/11 of B group phosphorus to A group gave a better order of placing for the soils on the basis of these sums, when compared with the order of placing on the basis of crop responses, than did adding all the B group phosphorus. In order to evaluate C group phosphorus nutritionally, various multiples of it have been added to these A + 6/11 B sums and the totals again arranged in descending order of magnitude of the phosphorus extracted. These are reported in Table 8. The use of 1/10 of C group places soils 3, 7, 15, 16, 17, 19, and 33 out of the order indicated in crop responses, while taking 1/40 of C group misplaces soils 5, 6, 7, 10, 13, 18, 19, 20, and 22. The use of 1/20 of C group for addition, however, arranged the soils in practically the identical order indicated by crop responses. It should be noted that the pH values for soils 18 and 20, as given in Table 1, may account for their relatively high responses, as may related conditions in the case of soil No. 1, a Portsmouth loam.

SUMMARY

A method of estimating the different forms of inorganic phosphorus in Maryland soils was developed. It is based upon the rates of solution of phosphate materials and the subsequent ease of determination by the blue colorimetric method. Briefly, this consists in the extraction of soil with two acid solutions which have selective extracting properties. These solutions were sufficiently buffered to maintain their pH values unchanged during extractions of calcareous as well as acid soils.

Solubility studies upon pure phosphate materials and in amounts similar to that found in soils were made to determine the solvent action of these two extractants.

Upon the basis of the data obtained a rapid extraction method was formulated to estimate the phosphorus present in the following three groups of materials: (A) Amorphous and finely divided crystalline phosphates of calcium, magnesium, and manganese; (B) amorphous phosphates of aluminum and iron; and (C) phosphorus absorbed upon hydrous oxides and that present in the form of apatite.

The actual amounts of B and C groups of phosphorus extracted from the soils was arrived at by continuous leaching studies.

Twenty-two representative Maryland soils were analyzed by this method and concurrently tested in pot experiments for response to phosphate fertilizations. This method of analysis placed the soils in practically the same order of phosphorus needs as did the pot tests.

LITERATURE CITED

1. Lohse, H. W., and Ruhnke, G. N. Studies on readily soluble phosphate in soils. Soil Science, 35: 355–409. 1933.
2. Meyer, A. H., and Truog, E. Improvements in the Deniges colorimetric method for phosphorus and arsenic. Ind. and Eng. Chem., Anal. Ed., 1: 136–139. 1929.
3. Robinson, W. O., Steinkoeinig, L. A., and Fry, W. H. Variation in the chemical composition of soils. U. S. D. A. Bul. 551. 1917.
4. Russel, J. C. Method for the continuous automatic extraction of soils. Soil Science, 36: 447–450. 1934.
5. Truog, E. The determination of the readily available phosphorus of soils. Jour. Amer. Soc. Agron., 22: 874–882. 1930.

AVAILABILITY AND FIXATION OF PHOSPHORUS IN HAWAIIAN SOILS[1]

A. FLOYD HECK[2]

THE soils of the Hawaiian Islands have been formed largely through the laterization of volcanic materials. Most of the soils, especially those of the higher altitudes, are of a reddish or reddish yellow color. Some of the lower lying lands and those of a more level topography of higher altitudes or those which have been at one time rather poorly drained are of a darker color and usually contain more organic matter than the red or yellow soils. Most of the red or yellow soils may be classed as laterites or lateritic soils and have a high sesquioxide-silica ratio. Much of the iron and aluminum exist in these soils in amorphous or colloidal forms as the oxides with varying degrees of hydration, and not as crystalline primary minerals as is generally true in most glacial or alluvial soils.

McGeorge (13,14,15)[3] has made rather extensive studies of phosphorus in these soils. As a rule he found their phosphorus content well above that for mainland soils, and yet it many of these laterites there is a deficiency of quickly available phosphorus. He found that the makai (lowlands) lands were usually higher in total and citric-soluble phosphorus than the mauka (highlands) lands. He also reported that low pH values in soils were usually correlated with low availability of native soil phosphorus and seemed to think that lands with less than 40 p.p.m. of citric-soluble phosphoric acid (P_2O_5) might respond to phosphate fertilization. However, little response has been obtained from phosphate fertilization in field tests on these soils even when they were known to be low in available phosphorus.

Recent articles by Hance (7), Ayres (1), and Davis (4) deal with phosphate fixation in Hawaiian soils. Although Ayres has taken water-insoluble phosphorus to mean fixed phosphorus, which may not always mean that the phosphorus is fixed in slowly available forms, his work does indicate that soils in certain districts have a much greater capacity for fixing phosphorus than those in other districts, and that most Hawaiian soils fix large quantities of phosphorus.

EXPERIMENTAL

Beginning in 1930, the writer has made a collection of 100 samples of Hawaiian soils and has used them for phosphorus availability and fixation studies. Since there seems to be a relation between the base saturation and both availability and the fixation of phosphorus in slowly available forms, the pH values were included in this work. The pH values were determined by the colorimetric method known

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[3] Figures in parenthesis refer to "Literature Cited," p. 884.

as the Truog soil reaction test. The quickly available phosphorus was determined by the Truog (17) method modified so as to use a ratio of solvent to soil of 400. The quickly available phosphorus obtained in this way corresponds to the readily available phosphorus of the Truog method except that it is slightly higher.

The capacity to fix phosphorus was determined by a method outlined by the author (10) and is based on the theory that slowly or difficultly available phosphorus is only slightly soluble in 0.002 N sulfuric acid in the ratio used. In this paper the writer is substituting the terms "quickly available" for "readily available" and "slowly available" for "difficulty available", for, after all, availability is very much a matter of rate of solution. The data for pH value, phosphorus availability, and fixation for the 100 Hawaiian soils are given in Table 1.

AVAILABILITY OF NATIVE SOIL PHOSPHORUS

The quickly available phosphorus content of Hawaiian soils is more variable than for most groups of soils. Although the tendency is for the amount of quickly available phosphorus to be generally low, the quantity found in some of these soils is abnormally high. The 100 Hawaiian soils have been grouped according to pH values and the availability of the phosphorus, and these data are given in Table 2.

Forty-six per cent of the soils studied contain 25 p.p.m. or less of quickly available phosphorus and many of these less than 10 p.p.m. or only mere traces. The 20 soils which show an availability of over 100 p.p.m. are either dark, gray, dark red, or brownish in color. This would tend to indicate that organic matter plays a very important rôle in maintaining a high availability for native soil phosphorus. One soil from field 6 of the Hutchinson Sugar Plantation Company has a fixation of 65% and still has 1,100 p.p.m. of quickly available phosphorus. This is a dark-colored soil and contains considerable organic matter which may be responsible for these two seemingly contradictory facts. Perhaps phosphorus in organic combination does not fix as readily as inorganic phosphorus, or is removed entirely from possible fixation.

Relation of pH values to availability.—Investigators have observed a relation between the pH value of a soil and the availability of its phosphorus. There appears to be a more or less definite pH value below which there is a very strong tendency for the quickly available phosphorus content of a soil to be low. Gaarder (6) has shown that 6.5 is the pH value where calcium phosphate has the lowest solubility. At this pH value, phosphorus tends to remain in the soil as calcium phosphate, thus making the availability of the native soil phosphorus greater than if the soil were more acid and the phosphorus could be changed more easily to the less soluble iron or aluminum compounds. At pH 6 the solubility of calcium, aluminum, and iron phosphates are approximately the same, and each of these bases have an equal chance in competition for phosphorus. At this pH value the amount of each of these phosphates formed depends upon the relative amounts of these bases present in a reactive state. At pH 6.5, calcium phosphate has only about one-third the solubility of either iron or alumi-

TABLE 1.—*The pH value, quickly available phosphorus, and the phosphorus fixation of 100 Hawaiian soils.*

Location, description, color, etc., of soil		pH value	Available phosphorus, p.p.m.	Phosphorus fixation %
Hawaii				
Hamakua Mill Co.				
Field 40K	yb*	5.4	14	98.5
Hutchinson Sugar Co.				
Field 6	d	5.9	1100	65.0
Field 15B, Exp 11	d + y	5.6	25	93.2
Kaiwiki Sugar Co.				
Field 31	ry	4.9	22	96.7
Olaa Sugar Co.				
Field 1, 2, 3,	yb	5.6	8	97.0
Paauhau Sugar Co.				
Field 7A	yb	5.7	24	94.5
Field 18	y	6.0	T	98.5
Pepeekeo Sugar Co.				
Field 20	yb	5.6	32	97.0
Kauai				
Grove Farm Co.				
Field 1, line	r	6.4	88	78.2
Field 1, kuakua	r	6.6	78	78.2
Field 4B		6.2	37	89.2
Field 8B-1	yb	5.3	8	94.5
Field 15A	by	5.3	26	83.5
Field 15A	yb	5.6	43	83.5
Field 15C	yb	5.9	21	90.2
Field 15D	yb	5.5	21	91.2
Field 16F, poor	ry	5.2	18	94.5
Field 16F, good	by	5.1	76	97.5
Field 17A, poor	by	5.5	27	90.7
Field 17A, good	by	5.5	40	85.0
Field 20A	by	5.6	45	93.7
Field 20D	by	6.1	30	92.5
Field 25	by	5.1	14	94.2
Field 27, virgin	by	5.1	T	92.0
Field 4A, (makai)	r	6.2	124	77.2
Grove Farm Co.—*Concluded*				
Field 17 (middle)	by	5.7	45	90.7
Field 31D (mauka)	d	6.9	152	72.0
Field 31, good	by	5.3	39	92.7
Field 34H	by	6.0	108	90.7
Field Wailua, alfalfa	d	8.0	860	00.0
Hawaiian Sugar Co.				
Field 31	by	6.0	17	83.0
Kekaha Sugar Co.				
Field E, (coral)	rb	8.0	210	35.0
Kilauea Sugar Co.				
Field 1A	by	6.2	88	98.5
Field 2D diseased	d	5.8	56	89.0
Field 4A makai end	ry	5.7	14	94.0
Field 4B line	y	5.8	14	96.0
Field 4B kuakua	y	5.6	56	96.0
Field 15F	by	5.7	51	92.0
Field 18P, very poor	y	5.0	8	98.5
Field 22B	ry	6.2	7	98.2
Field 25B	by	5.3	14	92.0
Field 25C	by	5.3	14	93.5
Field 28A	y	6.2	10	94.0
Field 28C	y	6.8	100	83.7
Field 33½	yb	5.5	9	93.7
Field 35A	y	6.5	20	90.5
Koloa Sugar Co.				
Field 15 (coral)	d	8.0	160	47.5
Lihue Plantation Co.				
Field 1	r	6.4	52	90.5
Field HM10C	rb	6.2	96	89.0
Field HM21		6.0	32	87.5
Makee Sugar Co.				
Field 1B	y	5.4	8	95.5
Field P.L.	g	8.0	12	70.5
McBryde Sugar Co.				
Field 10A	r	5.8	T	86.0

*y = yellow, yellowish; = red, reddish; b = brown, brownish; d = dark; g = gray.

TABLE 1.—*Concluded.*

Location, description, color, etc., of soil		pH value	Available phosphorus, p.p.m.	Phosphorus fixation %
Maui				
H. C. & S. Co.				
Field 8A	br*	6.8	47	55.5
Sample 30	g	8.0	105	21.2
Pioneer Mill Co.				
Field 11—plot P	d	6.9	420	27.5
Field 20	d	6.5	305	36.2
Field 27	d	6.9	215	36.2
Wailuku Sugar Co.				
Field 82	yb	6.4	110	66.2
Field 85	rb	6.3	120	72.5
Field 93	d	6.6	610	40.0
Oahu				
Ewa Plantation Co.				
Sample A	g	7.6	15	79.2
Exp. Sta. H. S. P. A.				
Makiki Station	yb	6.5	700	52.5
Manoa substation (1)	by	5.3	94	94.0
Manoa substation (2)	y	5.1	40	96.0
Waipio Substation				
Plat 15, kuakua	yb	6.3	38	77.0
Plat 15, line	yb	6.1	45	76.7
Honolulu Plantation Co.				
Red Hill (A)	r	6.3	230	57.5
Old soil under parent lava of (A)	ry	7.0	85	46.2
Kahuku Plantation Co.				
Field 1B	d	8.0	22	54.2
Oahu Sugar Co.				
Field 57	r	6.4	94	61.0
Waialua Agricultural Co.				
Field Helemano 2A	r	6.2	14	71.0
Field Kawaihapai 3A	d	6.8	395	46.2
Field Opaeula 2A	ry	6.8	63	63.2
Field Opaeula 6	r	6.8	15	64.5
Field Opaeula 16	br	6.4	7	83.0
Field Opaeula 18	rb	5.5	20	79.5
H. S. P. A.—6257	yb	6.8	220	56.2
Waimanalo Sugar Co.				
Field 6	rb	6.1	37	84.7
Field 22B	yb	6.3	78	82.0
Exp. Sta., A. H. P. C.				
No. 25	yb	5.6	6	98.2
No. 555	br	5.5	8	90.0
No. 622	r	6.1	8	84.0
No. 626	y	4.7	5	97.2
No. 631	by	5.0	8	93.5
No. 914	yb	6.1	350	50.0
No. 1591	r	6.4	9	78.2
No. 1594	yr	6.3	5	87.7
No. 1595	yr	5.8	8	81.0
No. 1597	yb	5.7	8	82.5
No. 1599	y	4.8	7	95.5
No. 3128	yr	5.4	10	81.5
No. 3911	by	4.9	6	95.2
No. 5836	rb	6.0	16	83.5
No. 5837	yr	5.8	30	78.0
No. 6459	rg	5.2	T	89.7
No. 10622	g	8.0	190	10.0
No. 10626	g	8.0	95	11.2
M. P. Co. Fld X, El. 2750	rb	5.6	25	96.7
M. P. Co. Fld X, sink at bottom	rb	5.4	30	95.7

*y = yellow, yellowish; r = red, reddish; b = brown, brownish; d = dark; g = gray.

num phosphates, and at this pH value or higher, other factors being equal, the calcium has a distinct advantage in holding phosphorus against the aluminum and iron. This relation seems to be borne out by the data on the 100 Hawaiian soils listed in Table 1. The frequency distribution of these soils, showing the relation of pH value and availability, is shown in Table 2.

TABLE 2.—*Relation of pH value to the quantity of quickly available phosphorus in 100 Hawaiian soils.*

Quickly available phosphorus, range in p.p.m.	Soils below pH 6.5		Soils of pH 6.5 or over	
	Number	%	Number	%
25 or less	41	54.0	5	20.8
26 to 50	17	22.4	1	4.2
51 to 100	11	14.4	5	20.8
Above 100	7	9.2	13	54.2
Total	76	100.0	24	100.0

Of the 76 Hawaiian soils with a pH value below 6.5, 54% have a phosphorus availability of 25 p.p.m. or less, and only 9% are above 100 p.p.m. In the group of 24 soils whose pH values are 6.5 or higher, 54.2% have an availability above 100 p.p.m. On mainland soils, the application of lime in the field practically always increases the availability of the native phosphorus, if sufficient lime is added to raise the pH value to 6.0 or 6.5. This, no doubt, is due in part to a disturbance of the chemical equilibrium in the direction of greater availability and also to the creation of a greater biological balance[4] due to both the lime and the increased availability of the phosphorus in the chemical equilibrium, resulting in an increase in the biological phase of the phosphorus equilibrium as a whole. This is in line with ideas set forth by the writer in a previous paper (12).

Forms of native soil phosphorus.—Soil phosphorus combined with calcium is generally considered to be quickly available, but if combined with iron or aluminum its availability is very much slower. Japanese investigators (16) report finding calcium, aluminum, and iron phosphates in soils in varying proportions. The writer (9) has shown that some soils give positive indications of containing calcium phosphate, while in others the phosphorus is largely held by iron. Many mainland soils show positive evidences of containing calcium phosphate, but most Hawaiian soils, especially those with pH values below 6.5, carry their phosphate mainly in the iron and aluminum forms. Fig. 1 shows the solubility curves for phosphorus of a Carrington silt loam and a soil from Field 18P, Kilauea Plantation, Kauai.

Curve A for the untreated Carrington silt loam indicates a small amount of calcium, together with some rather easily soluble aluminum phosphate. This soil has a pH value of 5.7 and contains 23 p.p.m. of quickly available phosphorus by the extraction method. The triangle

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[4] A biological balance may be considered the resultant of biological action in the soil in which nitrogen, phosphorus, or potassium is combined into organic form and is held against inorganic combinations.

abc represents the native calcium phosphate and corresponds rather closely with the amount of quickly available phosphorus. This close correspondence has been found in most soils where comparisons have been made.

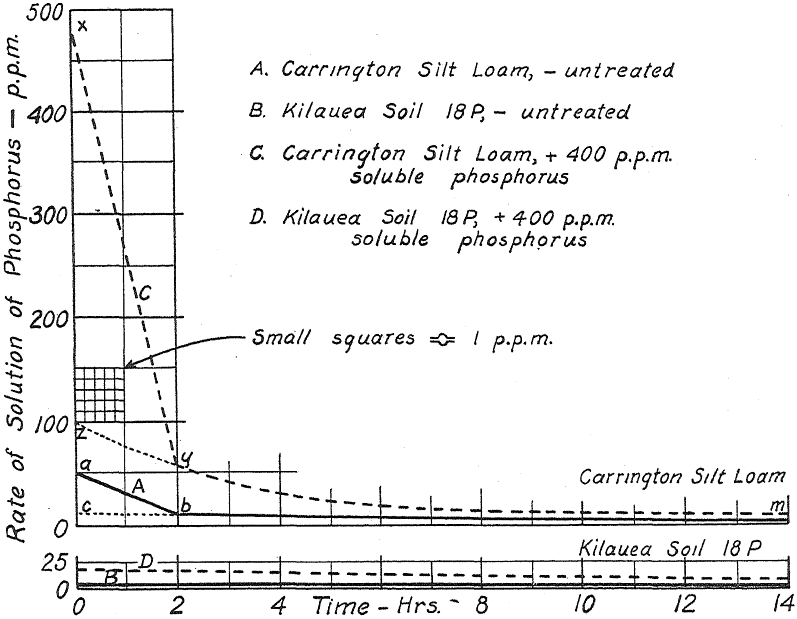

FIG. 1.—Solubility curves for the native and applied phosphates in Carrington silt loam and Kilauea soil, field 18P. The data for these curves were produced by leaching the soils with sulfuric acid at pH 3, and show the rate of solution of the phosphorus. The area under the curves represents the amounts of phosphorus dissolved in any given unit of time.

In curve B for Kilauea soil, field 18P, there is no indication of any calcium or easily soluble phosphates of any kind. The solubility curve indicates that the phosphorus in this soil is practically all in the form of basic iron phosphate, and is of the nature of the phosphorus in dufrenite ($Fe_2(OH)_3PO_4$) (9). This is true of a great many of the red and particularly of the yellow, Hawaiian laterites of the mauka lands. Some of the makai lands, which are more or less alluvial and have a darker color, are usually higher in calcium, have higher pH values, and contain more quickly available phosphorus. Most of these makai soils have a solubility curve for phosphorus which definitely indicates the presence of calcium phosphate, but these soils are comparatively few and nearly all confined to the lower lying lands.

AVAILABILITY OF APPLIED PHOSPHORUS

When phosphate fertilizers are applied to soils, the availability of the applied phosphorus depends upon the form of the phosphorus applied and also on the kind and amount of fixation taking place in the soil. If there is little or no fixation, the availability depends entirely upon the form and distribution of the phosphorus applied If the applied phosphorus is soluble and takes the form of calcium phosphate, it is quickly available, but if it is fixed as iron phosphate and particularly as the basic iron phosphate (dufrenite), it becomes so very slowly available that to a large extent it may be considered lost to the plant. Phosphorus may be fixed in either the quickly or the slowly available form, but the term fixation in this paper refers to that phosphorus fixed in the slowly available form. The distribution of the 100 Hawaiian soils according to their capacity to fix phosphorus is given in Table 3.

TABLE 3.—*The distribution of 100 Hawaiian soils according to their capacity to fix phosphorus.*

	Percentage of total number
Soils whose capacity to fix phophorus is	
95% or over	19
90% or over	44
80% or over	64
70% or over	77
60% or over	82
50% or over	88
Below 50%	12

Phosphorus fixed in slowly available form.—The amount of phosphorus fixed by soils varies greatly. In the great majority of the laterites, the capacity to fix phosphorus is very high. In this group of 100 soils, 64% fix 80 % or more, 44% fix 90% or more, and 19% fix over 95% of the soluble phosphorus applied. Compared with most mainland soils, this is very high. Of the nearly 200 fixation determinations made on soils from the states east of the Mississippi river, 50% had a fixation less than 40% of the applied soluble phosphorus, and it was the exceptional soil that had a fixation of 90% or more.

Although nearly half of the samples used in this study are from the island of Kauai, there are sufficient samples from each of the other islands to give a rather fair idea of the difference in the capacities of the soils from the different islands to fix applied phosphorus. Even from the limited number of samples available, it is rather easy to see that the soils of the island of Hawaii stand highest in their capacity to fix phosphorus, followed closely by the soils of Kauai and Oahu. The samples available from Maui indicate a much lower fixation for the soils of that island than for those of the other three, but the predominance of dark samples indicates that perhaps these samples are not altogether representative of the soils of Maui as a whole, and that more representative samples would show a higher fixation.

Of the 12 soils having a fixation less than 50%, 11 were either dark, gray, or brown and only one was yellowish in color. This was an old soil, which after its formation, had been covered by a lava flow which perhaps dehydrated some of the iron oxide and rendered it inactive. As a rule, the low-fixing soils are usually dark and quite often contain lime. These dark soils are, as a rule, not laterites and contain less active iron and aluminum and more organic matter and lime, all of which tend to lower fixation. Although there seems to be a tendency for the presence of organic matter to lower fixation, this does not hold true for the soils on the island of Hawaii. In these soils there is sufficient organic matter to give many of them a brown color, but at the same time most of them show considerable yellow. So it appears that if the hydrated iron oxide is present, it is an active fixing agent even in the presence of enough organic matter to mask its color rather completely.

The figures available indicate that the reddish yellow to yellow soils have the highest fixation of any group of island soils. The soils of Kilauea, Grove farm, and Lihue on windward Kauai nearly all show this tendency. Throughout the figures in Table 1 can be seen the tendency for the yellow in a soil to be correlated with high fixation. This is in accord with the theory that fixation by iron is brought about largely by the hydrated oxides (5), such as ferric oxide monohydrate, or perhaps the dihydrate, should this substance exist in nature. In the amorphous or finely divided state these substances are more or less yellow and tend to impart that color to the soil. However, the red of the hematite and the dark color or organic matter masks the yellow of the hydrated iron and results in a dark high-fixing soil such as is found on Hawaii.

Forms of fixed phosphorus.—The form in which phosphorus is fixed in the soil depends on the nature of the soil and the amount of active iron and aluminum which it contains. If the soil contains sufficient active iron or aluminum, a large amount of the applied phosphorus will be fixed in these forms, but if these substances are low there will be a greater tendency for more of the applied phosphorus to be found in the soil in the calcium form.

Curve C (Fig. 1) shows the approximate amount of phosphorus recovered in the different forms after an application of 400 p.p.m. of soluble phosphorus to a Carrington silt loam. The area of the triangle *xyz* minus the area of the triangle *abc* represents the amount of applied phosphorus recovered as calcium phosphate, and the triangle *zmc* roughly approximates the aluminum or easily hydrolyzable iron phosphate. The balance may be considered basic iron phosphate whose rate of hydrolysis is very slow. In round numbers, with this Carrington silt loam, 43% of the applied phosphorus was found as calcium phosphate, which is quickly available, 34% as aluminum or easily hydrolyzable iron phosphate, and the balance, or 23%, as iron phosphates which are very slowly available.

Miami silt loam is fairly typical of low-fixing soils. In this type it is not uncommon to find as much as 90% of the applied phosphorus in the calcium form, the amount depending somewhat on the pH value of the soil.

The solubility of the phosphorus fixed in the Kalauea soil, field 18P, is shown in curve D (Fig. 1). In this case no calcium or aluminum was found and only a very small amount of slightly hydrolyzable iron phosphate. By far the greater part of the phosphorus applied to this soil was fixed in the dufrenitic form or basic iron phosphates, or phosphates of this nature. This is a typical high-fixing laterite (98.5%) and characteristic of many of the phosphorus-deficient soils of Hawaii. In soils like this, the fixed phosphorus is so slightly available that field tests with soluble phosphorus on these soils have usually shown little or no response and the erroneous conclusion has been reached that these soils are not deficient in available phosphorus.

It has been shown (9) that when soluble phosphate is applied with irrigation to the surface of these soils, it is practically imposible to obtain penetration, and the applied phosphorus remains in the immediate surface fixed in forms whose availability is so slow as to render the phosphorus practically unavailable.

DISCUSSION

Because of the low availability of the native phosphorus in most Hawaiian soils, there should be a response to phosphorus fertilization in the field, but with very few exceptions, like those at Pioneer Mill on Maui, this is not the case. In Hawaii, the high surface fixation of the applied phosphorus in very slowly available forms is, no doubt, the outstanding factor responsible for this lack of response to phosphorus fertilizers in the field. In Mitscherlich tests (3), responses have been obtained with Sudan grass from soluble phosphorus used on these laterites, but field tests with cane have not shown corresponding responses. An explanation for this inconsistency may be that in the Mitscherlich tests the applied phosphorus is distributed uniformly throughout the entire soil mass and also that the fixation process requires some time to come to complete equilibrium in the soil. For the latter reason a quick-growing plant like Sudan grass would be able to take advantage of this lag in fixation which might be as much as 20 to 30% for 30 to 60 days, but which a longer growing crop like cane could not do. Another factor which may help to explain the response to phosphorus in Mitscherlich's pot tests is that the sand in the mixture will present surfaces incapable of fixing phosphorus and which hold some phosphorus in quickly available form. In addition, it is doubtful whether responses from Sudan grass would necessarily hold true for cane.

The need for corrective measures to better the phosphorus situation in these soils is indicated in many ways. In addition to its influence on the growth and maturity of the cane, the effect of available phosphorus in reducing the damages by diseases has often been observed. The author (8) has pointed out its apparent relation to brown stripe and eye spot and Carpenter (2) has observed the effect of low phosphorus availability on the ravages of *Pythium* root rot. He says, "Deficiencies of available phosphate promote *Pythium* root rot and growth failure of cane varieties which are not particularly sensitive to increased nitrogen. In root studies with Hamakua soil, H 109, D 1135, and Yellow Calledonia, for examples, were particularly sensitive to the low phosphate availability and resulting root rot."

The facts show that the majority of the Hawaiian laterites are not only low in available phosphorus but at the same time have a high capacity for phosphorus fixation in slowly available form. The practical solution of this problem is not so easy. By liming the soil to a pH of 6.5 or higher (9, 11), it is possible both to retard the rate of fixation of phosphorus and reduce the amount fixed. The maximum reduction that can be expected from this factor will not exceed 25 to 30% of the applied phosphorus. At the same time there will be a slight increase in phosphorus availability. The advantage from lime could not be very great in these soils, for after liming, most Hawaiian soils would still have a fixation of 60 to 75%.

Placing of the phosphate fertilizer in the line within the root zone would also help as well as the use of phosphates which do not fix so readily. The reverted phosphates have about the same fixation rate as soluble phosphates, but their initial fixation is less and as a result the lag in fixation is greater giving some slight advantage to this form. The phosphorus in rock phosphate, which is mostly Collophane ($3Ca_3(PO_4)_2.nCa(CO_3,F_2,SO_4,O)$, has a very low fixation, but at the same time its availability for cane is also low. Some beneficial effect has been seen when this material was incorporated in the soil with the seed, but as a rule there has been little response.

With the present knowledge of fixation, a combination of the use of a phosphate of lower fixation and an increase in the biological activity in the soil seems to promise the best and most practical solution of the problem. By the utilization of as much crop residue as possible and the proper use of the waste molasses along with phosphorus, the biological activity can be utilized to build up a biological balance and increase the active organic matter in Hawaiian soils so that the phosphorus in rock phosphate or even the native soil phosphorus may be made more available by increasing the biological phase of the phosphorus equilibrium. A phosphate fertilizer combining the non-fixing properties of rock phosphate and the availability of superphosphate used in combination with waste molasses should create a condition in the soil which would tend to increase phosphorus availability.

SUMMARY

This work consists of a study of the availability of native phosphorus and also the extent and form of phosphorus fixation in Hawaiian laterites.

The availability of the native phosphorus in Hawaiian lateritic soils is more variable than in most soils from continental United States. As many as three-fourths of these laterites have a phosphorus availability low enough that they should respond to phosphorus fertilization. Laterites with a pH value below 6.5 are usually low in available phosphorus. Forty-six per cent of the soils reported showed less than 25 p.p.m. of available phosphorus. Native phosphorus in these laterites of low phosphorus availability is largely in the form of basic iron phosphate with a solubility of phosphorus similar to that of dufrenite.

When soluble phosphorus is applied to these laterites, the majority of them fix over 80% of the applied phosphorus in slowly available form. Most of the applied phosphorus is fixed in the soil as the basic iron phosphates, with perhaps some aluminum phosphates. Seldom is much of the applied phosphorus held in these laterites in the form of calcium phosphate.

LITERATURE CITED

1. AYRES, A. Phosphate fixation in Hawaiian Soils—II. Hawaii Planters' Record, 38: 131–145. 1934.
2. CARPENTER, C. W. *Pythium* root rot. Hawaii Sugar Planters' Assoc. Rpt. Com. Charge Exp. Sta.: 32–33. 1934.
3. COOK, D. A. Mitscherlich pot method of testing soils. Hawaii Sugar Planters' Assoc. Proc. 51st. Ann. Meet. 1931.
4. DAVIS, L. E. Phosphate fixation in Hawaiian Soils—III. Hawaii Planters' Record, 38: 206–215. 1934.
5. FORD, M. C. The nature of phosphate fixation in soils. Jour. Amer. Soc. Agron., 25: 134–144. 1933.
6. GAARDER, T. Die Bindung der Phosphorsäure im Erdboden. Vestlandets Forstl. Forsøksta. Meddel., 14. 1930.
7. HANCE, F. E. Phosphate fixation in Hawaiian soils. Hawaii Planters' Record, 37: 182–196. 1933.
8. HECK, A. FLOYD. Some indications of a relation of soil fertility and plant nutrition to cane diseases in Hawaii Jour. Amer. Soc. Agron., 26: 381–389. 1934.
9. ——————. Phosphate fixation and penetration in soils. Soil Science, 37: 343–355. 1934.
10. ——————. A method for determining the capacity of a soil to fix phosphorus in difficulty available form. Soil Science, 37: 477–482. 1934.
11. ——————. Effect of the degree of base saturation of a soil on its capacity to fix phosphorus in difficulty available form. Soil Science, 38: 463–470. 1934.
12. ——————. The biological effect of available phosphorus in Hawaiian soils. Jour. Amer. Soc. Agron., 27: 847–851. 1935.
13. MCGEORGE, W. T. Phosphate fertilizers for Hawaiian soils, and their availability. Hawaii Agr. Exp. Sta. Bul. 41. 1916.
14. ——————. A study of the phosphates in the Island sugar lands. Hawaii Sugar Planters' Assoc. Exp. Sta. Agr. and Chem. Bul. 47. 1923.
15. ——————. The influence of silica, lime and soil reaction upon the availability of phosphates in highly ferruginous soils. Soil Science, 17: 463–468. 1924.
16. OSUGI, S., YOSHIE, S., and NISHIGAKI, N. On the identification of phosphate compounds in soil. Bul. Agr. Chem. Soc. Japan, 7: 84–85. 1931.
17. TRUOG, E. The determination of readily available phosphorus of soils. Jour. Amer. Soc. Agron., 22: 874–882. 1930.

INFLUENCE OF PARENT MATERIAL ON SOIL CHARACTER IN A HUMID, TEMPERATE CLIMATE[1]

R. S. STAUFFER[2]

BEGINNING in east-central Illinois and extending on to the northern boundary of the state, there occur certain soils that possess rather undesirable physical properties. Attention was called to these soils in 1915 when a soil survey of Livingston County was being made, and their occurrence in adjacent counties was noted after that time. They were more clearly recognized and described in 1929 when a soil survey of Ford County was being made. Prior to the Ford County work, these soils were not understood, their extent appreciated, nor their significance realized. As a result, soil maps made by the Illinois Soil Survey before 1929 do not distinguish these soils, although they occur in large areas in the whole northeastern quarter of the state.

Since the parent material seemed to be responsible for the properties of these soils, a study of the soils and their respective parent materials was undertaken. The results of a part of this study are reported in this article.

REVIEW OF LITERATURE

That the properties of most soils are influenced, to some extent at least, by the nature of their parent materials has been recognized since systematic study of soils began. In some of the older schemes of classification the influence of parent material was probably over-emphasized. On the other hand, following the interest in the Russian system of soil classification developed in the United States, the tendency for a time was to stress the influence of climatic forces on soil character almost to the exclusion of the parent material influence. It is true that the soil-forming forces of a region tend to produce soils of similar characteristics from materials that are geologically different. As a result, there exist large areas of soils having some characteristics in common which correspond to the great climatic belts. But within such areas the soils may vary widely, and in some cases at least, these variations are due to the nature of the parent material.

The literature contains many references to the influence of parent material on soil characteristics, but most of these references seem to be based on observation alone. Very little work has been reported in which definite studies were made for the purpose of determining how parent material may affect the soil derived from it. There are, however, some outstanding examples of such influence, and a few of these are noted here.

In his discussion of endodynamomorphic soils, Glinka (3)[3] states that the characteristic of humus accumulation in Rendzinas is very striking since these

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[1] Contribution from the Department of Agronomy, University of Illinois, Urbana, Ill. Part of a thesis submitted in partial fulfillment of the requirements for the degree of doctor of philosophy. Published with the permission of the Director of the Illinois Agricultural Experiment Station. Received for publication September 21, 1935.

[2] Associate in Soil Physics.

[3] Figures in parenthesis refer to "Literature Cited," p. 894.

soils "lie usually in regions in which the external soil-forming forces are not favorable to the accumulation of humus, such as those operating in the Podsol zone."

The soils of the Black Belt of Alabama are commonly interpreted as being an example of parent-material influence. One of these, Houston clay (4) formed from chalky limestone of the late Cretaceous period, is a dark-colored, granular, fairly well-drained soil. Lufkin clay, located nearby but formed from marine clay, is lighter colored, non-granular, very plastic and sticky when wet, and poorly drained.

In glaciated areas where other conditions are very similar, soils vary a great deal because of local differences in the drift. This is well illustrated by the soils of northeastern Ohio. According to Conrey (2), in areas where the underlying rock is shale, and hence there is a relatively greater amount of shale in the drift, the material which forms the soils is a heavy clay. Over the sandstone areas, where sandstone makes up a larger proportion of the drift, the soils have a coarser texture.

PLAN OF THE INVESTIGATION

After some preliminary work, three soil types, all prairie soils, were selected for study. Two of these, designated Clarence silt loam and Elliott silt loam by the Illinois Soil Survey, have very slow subsurface drainage. The other, Saybrook silt loam, is sufficiently open and porous to drain readily.

Both field and laboratory studies were made. The field work included a study of the area from the standpoint of topography, slope, drainage, and nature of parent material.[4]

For the laboratory work, large samples averaging about 15 kilos, were taken by horizons. In every profile at least one calcareous horizon was included, and in several cases, more than one. The deeper samples were secured for the studies on parent material. All samples were taken on very similar slopes of about 1 to 1.5%.

The samples were divided into two fractions by a 2-mm sieve, and the total percentage of the coarser fraction was determined. In the parent materials the lime concretions coarser than 2 mm were separated from the rest of the gravel.[5] The finer fractions were subjected to other determinations, including mechanical analysis, carbonate content, organic carbon, and hydrogen-ion concentration.

DESCRIPTION OF THE AREA

The soils used in this study occur in the Bloomington and Marseilles morainal areas of the Middle Wisconsin Glaciation and are found extensively developed in Ford County, Illinois. The relief of the area is not great, ranging from an elevation of 700 feet above sea level in the northern part of the county to 830 feet in the southwestern part. The change in elevation between these two points is gradual. Due to the presence of low morainal ridges, the surface is irregular but not rough. The principal surface features are a result of the irregular deposition of drift. For the most part, the topography ranges from undulating to gently rolling.

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[4] As used here, parent material includes all calcareous horizons, even though they have been somewhat affected by weathering. These horizons are designated by the letter D.

[5] The term gravel included all particles, except lime concretions, that would not pass through a 2-mm sieve.

This area occupies a comparatively elevated position from which streams radiate in all directions. As a result, no large streams cross the county and no deep valleys occur there. The drainage systems are very youthful and the surface run-off from much of the area does not have ready access to stream channels. However, there is sufficient slope to the surface in most cases that surface run-off passes off readily.

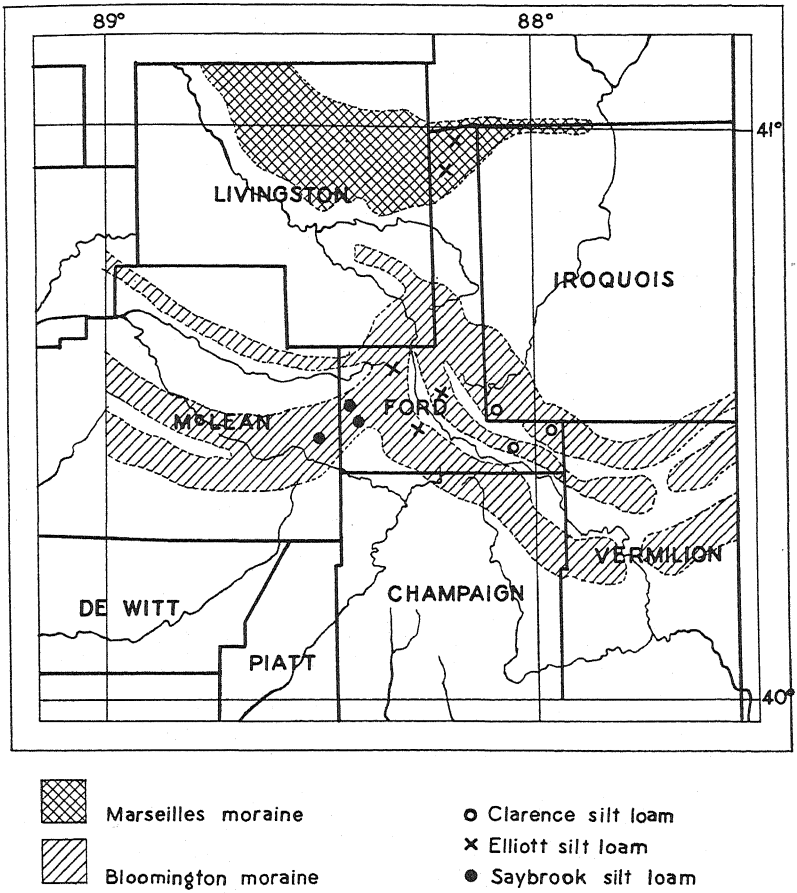

FIG. 1.—Group of counties in east-central Illinois showing the morainal areas and the locations where soil samples were taken.

The area included in this study, no doubt, received some loess, but the deposit is so thin that it cannot be identified with certainty. The drift ranges from 150 to over 200 feet in thickness. West of the reentrant angle, which occurs in the moraines of southwestern Ford County (Fig. 1), drift contains more sand and gravel and is more open and porous than that of the rest of the county. North and east of this angle, the drift is compact and plastic and does not permit water to pass through readily. Still further east, much of the drift is so impervious that percolation of water is very seriously interfered with.

The parent material of Saybrook soil is much more uniform in physical composition than that of Clarence or Elliott. In the areas where Clarence and Elliott soils occur, there are many small pockets of gravel and sand which influence the nature of the soils found in the immediate vicinity. There are also small local areas where the parent material contains no gravel, as low as 3% sand, and as high as 70% clay. Such material is very impervious, and where it occurs within 40 inches of the surface, has a decided influence upon the properties of the upper horizons of the profile.

The average annual precipitation of this region is about 36, which is usually well distributed throughout the year. The temperature is characteristic of a continental climate and records show it has ranged from 25° below 0° to 110° above. The mean annual temperature for the 10-year period, 1925 to 1934, inclusive, was 52.5°.

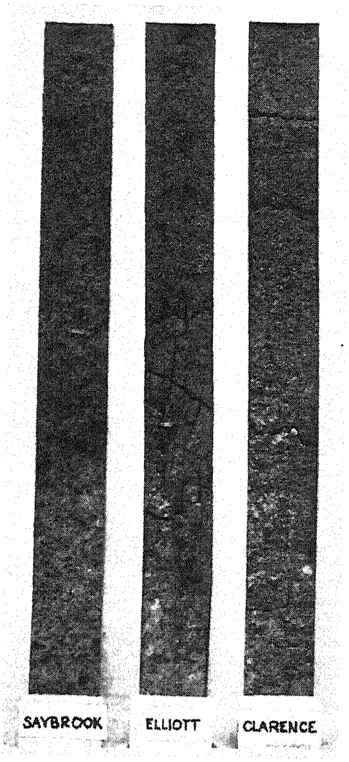

Fig. 2.—Profile samples of the soils included in this study.

DESCRIPTION OF THE SOILS

Fig. 2 shows fairly well some of the differences in these soils. The A_1 horizon of Saybrook, which ranges from 8 to 9 inches in thickness, is a friable silt loam, finely granular, and dark brown in color. The A_2 horizon is usually about 7 inches thick and is similar to A_1, but differs physically in being more plastic and lighter in color. The A_3 horizon is a transition zone and partakes of the properties of both the A_2 and the B horizons. The B horizon, usually from 7 to 8 inches in thickness, is only slightly plastic and plant roots penetrate it readily. A distinct C horizon[6], of 3 to 4 inches, is always present. The whole profile shows the influence of good drainage. Even the calcareous drift, which is encountered at a depth of 30 to 35 inches, has a decidedly yellowish cast and is readily permeable.

Clarence soil possesses characteristics of a decidedly different nature. The A_1 horizon, which is commonly about five inches thick, is more plastic and is in a poorer physical condition than the A_1 of

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[6] As used in this article, the C horizon is that portion of the soil profile between the B horizon and the calcareous parent material.

Saybrook. The A_2 horizon averages about five inches in thickness, and is only slightly more plastic than the A_1. The A_3 horizon, which is ordinarily about four inches in thickness, is decidedly more plastic than the A_2. The color of the A horizons of Clarence is more gray and less yellow than those of Saybrook. The B horizon, usually from ten to twelve inches thick, is very sticky and plastic when wet, and very hard when dry. Plant roots do not enter it readily, and where characteristically developed, very few roots penetrate the mass. Those that do penetrate this horizon are found chiefly in the cracks or natural cleavage planes. The imperfect root penetration probably accounts for the fact, at least in part, that unless the rainfall is very well distributed throughout the growing season, crops do very poorly on this soil. Usually no true C horizon is discernible, the B horizon passing abruptly into the calcareous material. There is evidence of considerable sheet erosion where this type occurs, even where there is very little slope to the surface. Surface drainage is usually good, but the whole profile shows evidence of poor underdrainage.

Elliott soil is intermediate between Clarence and Saybrook in most respects. It is a better agricultural soil than Clarence, but not as good as Saybrook. The A horizons are thicker and more friable, and the B horizon is not so plastic or impervious as in Clarence. Usually, as in Clarence, no true C horizon occurs in the profile, and although under-drainage is somewhat better, the characteristics of the profile are those of a poorly drained soil.

LABORATORY STUDIES

Since glacial drift is likely to vary quite widely even within small areas, the samples for studies on gravel were carefully selected so as to be as nearly representative of the particular soil type as possible. Further, as mentioned previously, the samples were large so they would be more nearly representative of the material sampled.

The samples were brought into the laboratory and while still moist were put through a 2-mm sieve. The portion that was too coarse to pass through the sieve was washed in distilled water to remove the fine particles. This fine material was thoroughly mixed with the original finer fraction. The whole sample was permitted to become air dry and the percentage by weight of the coarser material was determined.

Since lime concretions are secondary products, and since a considerable portion of the coarser material is made up of lime concretions, these were separated so that a better idea of the nature of the original material could be obtained.

The results of the gravel determinations are given in Table 1.

Mechanical analyses were made of the material that passed through a 2-mm sieve by the method essentially the same as described by Winters and Harland (5). The percentages of total sands and of $5\text{-}\mu$ and $1\text{-}\mu$ material were determined. These results are also given in Table 1.

In soils as young as those used in this study, the degree of weathering and leaching of the upper horizons of the profile is undoubtedly

TABLE 1.—*Data on the three soil types, Clarence silt loam, Elliott silt loam, and Saybrook silt loam.*

Horizon	Depth, inches	Lime concretions %	Gravel >2.0 mm %	Sands 2.0–.05 mm %	Clay <.005 mm %	Colloid <.001 mm %	pH	$CaCO_3$ equivalent %	Organic carbon %
				Clarence Silt Loam					
A_1	0–5	—	0.1	9.4	38.5	21.0	5.9	—	2.71
A_2	6–10	—	0.6	7.9	40.0	23.0	5.9	—	2.15
A_3*	11–14	—	—	4.0	49.4	33.1	5.8	—	1.03
B	15–25	—	0.4	6.1	63.0	40.5	6.6	—	0.55
D_1	26–32	0.2	1.4	5.5	58.3	36.1	8.0+	14.7	0.38
D_2	33–39	1.7	1.2	5.8	57.8	33.3	8.0+	19.3	0.27
D_3	40–46	0.4	2.5	5.7	52.6	30.1	8.0+	20.3	0.35
D_4*	47–70	—	—	5.6	53.6	30.6	8.0+	20.3	0.31
				Elliott Silt Loam					
A_1	0–7	—	0.4	8.7	38.2	21.1	6.3	—	3.00
A_2	8–13	—	0.4	7.6	41.4	24.2	6.1	—	1.72
A_3	14–18	—	0.8	9.1	48.2	29.6	6.0	—	1.00
B	19–30	—	0.7	8.4	56.4	35.6	6.5	—	0.74
D_1	31–36	0.1	2.9	10.5	46.7	28.5	8.0+	16.4	0.55
D_2	37–45	0.5	5.9†	9.7	44.7	26.7	8.0+	22.5	0.40
D_3	46–56	0.1	3.7	10.0	40.2	23.4	8.0+	23.2	0.46
D_4*	57–70	—	—	12.1	42.3	24.5	8.0+	20.9	0.47
				Saybrook Silt Loam					
A_1	0–9	—	2.00	12.3	34.3	19.2	6.6	—	2.64
A_2	10–16	—	1.3	11.3	37.8	24.5	6.1	—	1.52
A_3*	17–21	—	—	11.8	41.9	29.5	5.9	—	0.94
B	22–30	—	3.4	19.9	44.7	31.3	6.4	—	0.66
C	31–34	—	3.8	24.3	41.7	27.5	7.5	—	0.49
D_1	35–45	0.3	7.7	23.7	31.5	19.6	8.0+	17.0	0.40
D_2	46–52	1.0	7.1	23.9	28.8	16.8	8.0+	22.5	0.36
D_3	53–68	2.1	5.6	24.7	29.5	16.8	8.0+	22.3	0.39
D_4	69–74	0.1	6.4	23.7	29.4	16.7	8.0+	21.2	0.36

*Percentages of gravel were not determined on the A_3 of Clarence or Saybrook, nor the D_4 of Clarence or Elliott.

†One large pebble happened to be in this sample. If it were not included the percentage would be 3.3.

influenced to considerable extent by the nature of their parent material. It seemed desirable to compare these soils with respect to the intensity of leaching, and since hydrogen-ion concentration is probably the most convenient method for this purpose, such determinations were made. The quinhydrone electrode method was used for all determinations, but in order to check the results, determinations on 15 selected samples were made by the hydrogen electrode method. The results secured by these two methods checked very closely, and it was assumed that the results secured by the quinhydrone method were correct.

The percentage of inorganic carbon was determined by a method similar to the one described by Clark and Collins (1) except in two respects. They used a stirrer to keep the acid and soil well mixed, and continued the aspiration for 5 hours or more for each determination; while in the work reported here, a shaker was used and the aspiration continued for 1 hour. A longer period of aspiration did not seem necessary, because there was no increase in the weight of the absorption bulb after that length of time.

The results in Table 1 are reported in percentages as calcium carbonate equivalent. These figures give some idea of the high percentage of lime in these parent materials.

Since the amount and distribution of organic matter in soils are likely to vary with variations in soil character, the content of organic carbon was determined. The method used is described by Winters and Smith (6). The depths of horizons are also included in the table to show especially the differences in distribution of the organic matter.

DISCUSSION

There is a wide variation in the amounts of gravel in the parent materials of these three soils. Excluding the one large pebble mentioned previously in a D_2 of Elliott, the average percentages of gravel for Clarence, Elliott, and Saybrook parent materials are 1.7, 3.1, and 6.7, respectively. This is approximately in the ratio of 1:2:4. In the upper horizons of the profiles the average percentages are 0.4, 0.6, and 2.6. This is not in the same ratio as in the parent materials, due largely to the fact that the gravel of Saybrook material contains relatively more of the rocks other than limestone. The amount of gravel in the upper horizons of these profiles is quite low for drift-derived soils. This is particularly true for Clarence and Elliott, which do not contain as much as 1% of gravel in any of the upper horizons. There is probably enough gravel in Saybrook to exert considerable influence on its properties.

These soils, as well as their parent materials, differ widely from each other in the percentages of sand they contain. Saybrook parent material contains more than four times as much sand as Clarence and more than twice as much as Elliott. This undoubtedly helps to explain the fact that Saybrook soil permits rapid subsurface drainage, while Clarence and Elliott, but particularly Clarence, are rather poorly underdrained. In the upper horizons the differences in sand content are not so pronounced, but Saybrook soil contains considerably more than the others. There is wide variation in the sand content of the Clarence profile, both between the different horizons of the same profile as well as between corresponding horizons of different profiles, but the Elliott soil averages about 2% more sand than Clarence.

Probably the differences in the amounts of material 5μ and finer are chiefly responsible for the physical differences in these soils. The parent material of Clarence soil averages 55.6%; that of Elliott, 43.5%; and that of Saybrook, 29.8% of 5-μ material. When it is realized that these materials were acid pretreated for the mechanical analyses which reduces the 5-μ material considerably (5), it is readily apparent what a high percentage of clay Clarence parent material contains.

In the A horizons of these soils, the differences in the amounts of fine materials are not so great, but the B horizons show marked differences. Even in the B horizons the differences are not as pronounced as differences in the parent materials. The B horizon of Clarence contains only 8.0% more colloid than the average of the parent material, while Elliott contains 9.8% more than its parent material and Saybrook 13.8% more. This seems to indicate that actual soil development has not advanced as far in Clarence as in the other soils and not as far in Elliott as in Saybrook. This would probably be expected because of the impervious nature of the Clarence parent material.

Fig. 2 shows that soil structure has developed much deeper in Saybrook and Elliott soils than in Clarence. In the field it was frequently noticed that structure particles were apparently developing in the calcareous material of Clarence. No discernible C horizon occurred in the Elliott profile, but structure was not as generally nor as definitely developed in the calcareous material. In the Saybrook profile, the calcareous material was always massive and a distinct C horizon had developed.

As shown in Table 1, the hydrogen-ion concentration of Saybrook soil indicates a more mature profile than that of either Clarence or Elliott, and the Elliott profile shows the influence of soil-forming forces more than does Clarence. The pH of the B horizon is considerably higher in all cases than that of the horizons above. As may be noted in Table 1, this occurs at a shallower depth in Clarence than in the other soils, and yet the A horizons of Clarence show a lower pH than the A horizons of Elliott and Saybrook. It is true that plant roots do not extend as deeply into the Clarence profile as in the other soils, although the organic carbon determinations do not seem to indicate significant differences in the organic content of the deeper horizons of these soils. Whether the organic growth and decay are sufficient to account for the differences in pH of the surface horizons is questionable.

The results of inorganic carbon determinations show that the parent materials of all these soils are highly calcareous, with only small differences between them.

The organic carbon determinations show that the organic matter decreases very rapidly with depth in Clarence.

SUMMARY AND CONCLUSIONS

1. Three soil types, designated Clarence silt loam, Elliott silt loam, and Saybrook silt loam by the Illinois Soil Survey, were studied.

2. Although all these soils have been developed from calcareous, glacial drift of about the same age and have been subjected to very similar climatic and topographic conditions, they differ widely in their properties.

3. The differences in properties are due to differences in the nature of the parent materials.

4. The soils studied are all relatively young, but there are pronounced differences in the stage of development of their profiles. The Saybrook profile shows the most advanced stage of development and Clarence shows the least.

5. There is a smaller amount of gravel in the upper horizons of the profiles than in the parent materials, chiefly because of the removal of calcareous gravel by weathering. There is a relative increase in the amount of gravel in Saybrook because it contains more rocks other than limestone than do the other soils. The parent material of Saybrook contains the most gravel and sand, while Clarence contains the least. Of the material 5μ and finer, Clarence parent material contains the most and Saybrook the least.

6. There seems to be no significant differences between the parent materials in content of carbonates or of organic carbon.

7. Saybrook soil has developed a deeper profile than Elliott, which in turn has a deeper profile than Clarence. This greater depth of the Saybrook profile is due to the greater thicknesses of the A_1, A_2, and A_3 horizons than of the corresponding horizons of the other soils. Both Clarence and Elliott have thicker B horizons than has Saybrook.

8. The shallow profile of Clarence seems to be due to the fact that the weathering forces have not been able to penetrate its parent material rapidly. A large proportion of the fine material, 5μ and smaller, in the B horizon of the Clarence soil is not there as a result of weathering, but because it was present in the parent material.

9. Although there are differences in the A horizons of these soils, the outstanding differences occur in the B horizons and in the parent materials.

10. The data presented here show that where other factors concerned in soil formation, such as age of material, rainfall, temperature, topography, and vegetative cover, are very similar, soils may still vary widely in their properties due to differences in materials from which they are being formed. Further, the glacial drift varies greatly even within short distances, and these differences are reflected in the soils formed from it.

11. This study emphasizes the importance of a knowledge of the parent materials of soils in any system of soil mapping. Such knowledge is a valuable aid in securing consistent mapping over large areas. It further emphasizes the necessity of examining the soil profile to considerable depths, at least through the B horizon, if one is not to be misled by temporary conditions.

12. Parent materials will be responsible to some extent for the characteristics of all except the most highly weathered soils. Young soils may owe their characteristics more to their parent materials than to the weathering forces.

LITERATURE CITED

1. CLARK, N. A., and COLLINS, E. R. The gravimetric method for the determination of carbonates in soil. Soil Science, 27:407–414. 1929.
2. CONREY, G. W. The glacial sandstone and shale soils of Ohio. Ohio Agr. Exp. Sta. Bi-monthly Bul., 20, No. 4: 145. 1926.
3. GLINKA, K. D. Great Soil Groups of the World and Their Development. Translation by C. F. Marbut. (Page 230.) 1927.
4. SCARSETH, G. D., and STROUD, J. F. The Black Belt soils of Alabama. Amer. Soil Sur. Assoc. Rpt., 21: 174–189. 1930.
5. WINTERS, E., and HARLAND, M. B. Preparation of soil samples for pipette analysis. Jour. Amer. Soc. Agron., 22:771–780. 1930.
6. ——————— and SMITH, R. S. Determination of total carbon in soils. Jour. Ind. Eng. Chem., Anal. Ed., 1:202–203. 1929.

SOME FACTORS AFFECTING NODULE FORMATION ON SEEDLINGS OF LEGUMINOUS PLANTS[1]

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IN a very interesting article by Thornton (12),[3] published in 1929, observations and data are given which seem to show that alfalfa plants (*Medicago sativa* L.), after reaching the age of 2 or 3 weeks, secrete a substance from the roots which markedly stimulates the growth of legume nodule bacteria, and hastens nodule development on young seedlings growing in close proximity. Further experiments indicated that the effect was not due merely to nitrogenous compounds and sugars that may have diffused from the roots. These findings are of considerable scientific interest in connection with the relations existing between root nodule bacteria and their hosts.

Since these observations were reported, the writers have had occasion to carry out experiments dealing with the same phenomenon as well as with a number of other factors which influence nodule formation. Some of the more pertinent of the resulting data are reported below. A portion of the experiments was carried out in the greenhouse, some in an artificially illuminated growth chamber, and the remainder in a modified cold frame. In the case of the cold frame the plants were exposed to direct sunlight in good weather but kept under glass in stormy weather and at night.

The results are reported in terms of the percentage departure of the mean number of nodules per plant of the treated plants from that of the control plants for each day of harvest, the plus sign indicating more nodules and the minus sign fewer nodules on the experimental plants. There are also included weighted means for each treatment, based on total numbers of nodules and plants and covering the entire period of the experiment. The results were also calculated on the basis of percentage of plants with nodules. As the conclusions to which these data lead seem to be identical with those mentioned below, these latter figures are omitted. The number of plants per pot for each day's harvest is not given. It varied somewhat in the different experiments; for soybeans it was 4 to 15 and for alfalfa it was 26 to 82.

The plants considered were not limited to the smaller ones in the cultures since it was not found possible in the present work to make a separation, such as Thornton made, in which the younger plants showed the effect of the presence of older plants and the older ones did not. The effect as noted here, while for the most part of considerably smaller magnitude, was apparently of somewhat longer duration than in the case reported by Thornton.

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[1] Contribution from the Bureau of Chemistry and Soils, U. S. Dept. of Agriculture, Washington, D. C. Received for publication September 14, 1935.

[2] Associate Plant Physiologist and Senior Chemist, respectively. The authors are indebted to H. J. Morris for assistance in carrying out certain phases of the experimental work.

[3] Figures in parenthesis refer to "Literature Cited," p. 902.

EXPERIMENTS WITH SOYBEANS (*Glycine hispida* Max.)

SUMMER EXPERIMENTS

The experiments, reported in Table 1, were conducted in the greenhouse, using pots containing 6 pounds of washed, but unsterilized, nitrogen-free quartz sand. The sand was made up to 15% moisture with a nitrogen-free solution of the same composition as that used by Thornton (12). The corn (*Zea Mays* L.) and older soybeans of the summer experiment were planted on July 29 at the rate of 5 seeds per pot. The younger soybeans were planted on August 10 at the rate of 5 seeds per pot where older plants were present and 15 seeds per pot in other cases. All pots were inoculated at the time of planting the younger soybeans with 50 cc per pot of a 5-day culture of soybean bacteria.

The results show that the presence of older soybean plants somewhat favored nodule formation on younger soybean seedlings in agreement with Thornton's observations with alfalfa. Where corn was substituted for the older soybeans, the beneficial effect of the older plants was slightly greater, hence the effect was not specific for legumes. Nitrogen, either in the form of potassium nitrate or of asparagin, was in some cases slightly stimulating to nodule production where added in small amounts but was very inhibitory at higher concentrations. Sucrose markedly favored nodule formation.

FALL EXPERIMENT

The results of a partial repetition of the above experiments, carried out in the greenhouse during cooler weather, is also given in Table 1. In this case the older corn and soybeans were seeded at the rate of 6 seeds per pot on October 10 and the young soybeans at the rate of 12 seeds per pot on October 24. Each pot was inoculated with 50 cc of a soybean culture on October 21.

In this experiment the older soybean and corn plants not only did not favor nodule production on the younger plants but had a harmful effect, more marked in the case of soybeans. Potassium nitrate again decreased nodule numbers except in a few cases at the smallest rate of application. Sucrose favored nodule production but not to quite as great an extent as in the earlier experiment.

The harmful effect of the older plants on nodule formation in the October-November experiment is very probably due largely to the light deficiency at this time of the year, especially for soybeans. The older plants, particularly the soybeans, shaded the younger plants to such an extent as to cause a marked decrease in the size of the seedlings in comparison with those in the controls.

EXPERIMENTS WITH ALFALFA

ARTIFICIAL ILLUMINATION

In Table 2 (1st experiment) are reported the results of tests of the effect of older alfalfa, wheat (*Triticum sativum* Lam.), and corn plants on nodule formation on alfalfa seedlings grown under a bank of 10 Mazda lamps and 1 Cooper-Hewitt mercury vapor lamp en-

TABLE I.—*Effect of old plants, combined nitrogen, and sucrose on nodule production by soybean seedlings, results reported in percentage deviation of number of nodules per plant from the check.*

Age of plants, days	Percentage deviation caused by										
	Old soybean plants	Old corn plants	Potassium nitrate				Asparagin			Sucrose	
			1 mg. N	8 mg. N	40 mg. N	200 mg. N	8 mg. N	40 mg. N	200 mg. N	1 gm.	10 gm.
Summer Greenhouse Conditions											
12	+45	—21	—	—	—	—	—	—	—	—	—
13	+8	+51	+137	—3	+21	—84	+26	+11	—74	+79	+384
14	+15	+102	—	—	—	—	—	—	—	—	—
16	+54	+86	+26	—3	—65	—97	+2	0	—98	+203	+85
18	—	—	+78	+59	+15	—96	+123	+35	—69	+108	+37
20	—14	—8	—14	—6	—46	—94	—20	+24	—82	+22	—31
23	—	—	+3	+25	—8	—95	+31	+28	—93	—21	—12
Mean	+12	+36	+22	+20	—23	—96	+30	+24	—83	+47	+14

Late Fall Greenhouse Conditions

Age of plants, days	Old soybean plants	Old corn plants	Potassium nitrate				Sucrose		
			5 mg. N	25 mg. N	100 mg. N	200 mg. N	1 gm.	5 gm.	10 gm.
15	—31	—11	+11	—11	—74	—78	+56	+4	+4
16	—53	—64	—14	—35	—59	—79	+7	—3	+4
18	—58	—31	+11	—5	—73	—63	+36	+67	+29
21	—46	—17	+28	—8	—49	—62	+3	+39	+17
25	—63	—29	—35	—23	—38	—72	+21	+6	+29
Mean	—53	—29	—2	—15	—54	—70	+20	+24	+20

closed in glass (light intensity about 2,000 foot-candles), using a 12-hour daily period of illumination. The experiments were carried out in glazed pots holding 4.5 kg. of washed sand. After addition of the Thornton nitrogen-free nutrient solution, the pots were sterilized in the autoclave and planted with sterilized seeds. The wheat, corn, and older alfalfa seed were planted 14 days before those of the younger alfalfa. The cultures were inoculated with 10 cc of a 4-day culture of the alfalfa strain of nodule bacteria either at the time of planting the younger plants or a week earlier, as shown in the table.

After making allowance for the wide variations always so pronounced in experiments dealing with nodule numbers, the data show only a slight effect of the older plants. The time of inoculation, likewise, had a negligible influence.

COLD FRAME EXPERIMENT

In the second experiment, reported in Table 2, the methods used were similar to those used in the first experiment except that the pots were kept in a modified cold frame. The older plants were seeded on August 28 and the young alfalfa 2 weeks later. Some of the young alfalfa plants were inoculated by the addition of 10 cc of bacterial culture per pot; the others received seed inoculation only. Two samples of quartz sand were used, one merely washed, the other heated at about 425°C for 18 hours to destroy organic matter. The latter was a finer grained sand than the former.

The number of nodules produced (not shown in the table), although somewhat variable in some cases, showed very strikingly that the addition of a heavy inoculum increased the speed of nodule production and the number of nodules per plant.

Under both conditions of inoculation the older plants produced a favorable effect on nodule production in the majority of cases. In general, this effect was small but in the heated sand it was very marked, the mean effect being about three-fold. These figures are a very definite confirmation of the effect as reported by Thornton.

SAND EXTRACT EXPERIMENT

In another experiment, alfalfa, corn, and wheat were planted thickly in separate jars of sand containing 3 kg. of sand each. On the eleventh day after planting, the sand was carefully removed from the roots and extracted with cold water until about 1.5 liters of extract for each treatment and for an unplanted control had been collected. These extracts, after sterilization in the autoclave, were added, together with actively growing nodule bacteria, to cultures of alfalfa seedlings at the rate of 15 cc of extract per culture, each culture consisting of the seedlings from 100 seeds planted in 4.5 kg. of sand. An 18-hour daily illumination period with artificial light was used.

On the seventh day after seeding, an average of about 1.5 nodules per plant had formed and most of the seedlings had the first leaf fully opened. The extracts from the sand in which the plants had grown gave essentially the same effect as the plain sand extract. Incidentally, laboratory tests of these extracts, including that of the

TABLE 2.—*Effect of old plants on nodule production by alfalfa seedlings, results reported in percentage deviation of number of nodules per plant from the check.*

Age of plants, days	Percentage deviation caused by the presence of old plants													
	1st experiment*						2nd experiment†							
	Sand inoculated 1 week before planting			Sand inoculated at planting			Seed, only, inoculated			Sand inoculated with a heavy inoculum			Seed, only, inoculated, heated sand
	Alfalfa	Wheat	Corn	Alfalfa	Wheat	Corn	Alfalfa	Wheat	Corn	Alfalfa	Wheat	Corn	Alfalfa
7	—	—	—	—	—	—	—	0‡	—	— 41	+ 60	—64	+1168
8	—15	—67	—59	—50	—19	+81	+ §	—	+ §	+134	+195	+46	+ 177
9	+92	+18	+77	—12	—41	+19	— 31	+ 36	+ 54	+139	+ 65	+ 7	+ 500
10	—	—	—	—	—	—	+176	+283	—100	—	—	—	—
11	+ 1	+ 1	+65	+48	—13	+30	—	—	—	—	—	—	—
Mean	+29	+ 9	+55	+30	—17	+26	+ 31	+104	+ 70	+ 82	+ 99	—17	+ 291

*Artificial illumination used.
†Modified cold frame used.
‡No nodules on either the check plants or those grown with older wheat.
§No nodules on the check plants, but 0.01 and 0.07 nodule per plant on the plants grown with older alfalfa and corn, respectively.

sand in which plants were not grown, showed that the growth substance (3) required by these organisms was present in sufficient quantity in all cases to permit good bacterial growth.

DISCUSSION

The data presented here show that nodule formation on seedlings may be favored by addition of sucrose, by applying especially large numbers of active organisms, and sometimes by the presence of older legume or nonlegume plants. Small quantities of available nitrogen may occasionally be slightly beneficial but larger quantities retard nodulation.

These findings with respect to sugar and nitrogen are in general agreement with earlier work discussed elsewhere (2, 4); likewise, the favorable effect of heavy inoculations in hastening nodule formation is a commonly observed (13) phenomenon, even though the total number of nodules that will form is small in comparison with the number of bacteria added.

In considering the data dealing with the effect of older plants on nodule formation it is advisable to disregard the results of the fall experiment with soybeans because the harmful effect of the older plants on the smaller ones was due chiefly to shading. A summation of the remaining results shows 33 positive and 15 negative results (69% positive). Where the older plant was a legume the effect was 70% favorable; where a nonlegume the figure was 68% positive. If each experiment is considered as a whole (mean value of all the harvests of a given treatment), the number of positive values totals 13 and the negative ones 2 (87% positive). That a stimulation of nodule production by the presence of older plants with experimental ones did occur seems without question to be shown by these data. On the other hand, the effect did not appear with much consistency and in most cases was much smaller than that observed by Thornton. Only in the last experiment where a finer, heat-treated sand was used was the result comparable with his. It should be borne in mind that in Thornton's experiments, as well as in ours, the plant culture medium contained neither nitrogen nor sugar and hence was very unfavorable to the maintenance of the added bacteria in an active growing condition. Using a very different experimental technic (agar cultures), Löhnis (6) was unable to obtain any effect of older plants on nodule formation on clover seedlings.

The time required for the first nodules to form in our experiments with alfalfa was usually 7 to 8 days as compared with about 10 days in Thornton's experiments. Allowing 3 days for germination, nodule formation under our conditions occurred in 4 to 5 days after the first root hairs formed which according to Thornton and others, is about the minimum time possible. Obviously, the more rapidly nodules form on the control plants, the less opportunity for detecting nodule stimulation by any treatment. Incidentally, in these experiments nodule formation on alfalfa seedlings usually occurred at about the time of the opening of the first true leaf, as observed by Thornton. This is probably largely a coincidence, since nodule development is now known to depend largely upon the carbohydrate-nitrogen relationships (1, 2, 4, 5). If these relationships are satisfactory it apparently requires about the same length of time for the first nodules to develop as for the first true leaf to open.

The most probable explanation for the beneficial effect of the older plants (where observed) seems to be the favorable effect of plant roots on bacterial growth. The experimental results reported here are consistent with this idea. Roots may give off at least traces of nitrogen and of organic substances. There is also a constant sloughing off of organic material due particularly to the death of root hairs. In addition, the pH (10) immediately surrounding the roots may be more favorable for bacterial growth. These influences of roots on bacterial growth have been considered rather fully by other workers (7, 8, 9, 10, 11). Our results showing much greater effects in heated sand, where coenzyme R (3) could not have been present, than in unheated sand, where a laboratory assay showed it present in adequate amounts for good bacterial growth, suggest that this growth substance may also play a very large part in the effect of the rhizosphere.

Thornton's results, showing that an extract from sand in which older plants had grown both favored nodule formation and bacterial growth on nitrogen-free sucrose agar, are also pertinent. A portion of this improved growth must be attributed to the traces of nitrogen added in the extract, but in addition, it certainly contained coenzyme R, which is essential for the growth of alfalfa bacteria. This substance is abundant in green and dead plant materials and is present to some extent in soil and sand. Thornton suspected that the effect was due to an amino acid but pot experiments with asparagin gave negative results.

The beneficial effect of the older plants in Thornton's experiments apparently lasted for only a day or so and hence the phenomenon would seem to be chiefly of scientific rather than practical interest. Even this slight effect, observed only in very pure sand, would probably not be detectable in an ordinary cultivated soil containing organic matter and other food for bacterial growth.

SUMMARY

1. The effect of the presence of older plants, including alfalfa, soybeans, wheat, and corn, on the nodulation of either alfalfa or soybean seedlings growing in close proximity was studied in sand cultures. Under conditions where the light intensity was not limiting, 33 positive and 15 negative results were obtained. The percentage of positive results was approximately the same whether the older plants were legumes or non-legumes. This beneficial effect of the older plants did not appear with consistency and in most cases was much smaller than that observed by Thornton in his work with alfalfa.

2. In similar experiments, where older plants were not present, increased nodulation followed additions of sucrose and of a heavy inoculum. Small quantities of available nitrogen were sometimes slightly beneficial but larger quantities greatly depressed nodule formation.

3. Cold water extracts of sand in which alfalfa, corn, and wheat seedlings had been growing, produced no appreciable effect on nodule formation when added to cultures of alfalfa seedlings.

4. A logical explanation of the favorable effect of older plants on nodule formation seems to be the extreme favorableness of the rhizosphere to bacterial growth, this in turn being due in part to the liberation of the essential bacterial growth substance from the roots.

5. The practical importance of this effect under field conditions is probably negligible.

LITERATURE CITED

1. ALLISON, F. E. Importance of carbohydrate supply in legume symbiosis. Nature, 134: 144. 1934.
2. ———————. Carbohydrate supply as a primary factor in legume symbiosis. Soil Science, 39: 123–143. 1935.
3. ——————— and HOOVER, S. R. An accessory factor for legume nodule bacteria. Sources and activity. Jour. Bact., 27: 561–581. 1934.
4. ——————— and LUDWIG, C. A. The cause of decreased nodule formation on legumes supplied with abundant combined nitrogen. Soil Science, 37: 431–443. 1934.
5. FRED, E. B., and WILSON, P. W. On photosynthesis and free nitrogen assimilation by leguminous plants. Proc. Nat. Acad. Sci., 20: 403–409. 1934.
6. LÖHNIS, MARIE P. Investigations upon the ineffectiveness of root-nodules on Leguminosae. Centr. Bakt., 80: 342–368. 1930.
7. LYON, T. L., and WILSON J. K. Liberation of organic matter by roots of growing plants. Cornell Univ. Agr. Exp. Sta. Mem. 40: 1–44. 1921.
8. MININA, E. G. The acidity of root secretions (Russian). Bul. Biol. Sci. Res. Inst., U. of Perm, 5: 233–258. 1927.
9. STARKEY, R. L. Some influences of the development of higher plants upon the microorganisms in the soil. Soil Science, 27: 319–334; 355–378; 433–444. 1929. 32: 367–404. 1931.
10. THOM, C., and HUMFELD, H. Notes on the association of microörganisms and roots. Soil Science, 34: 29–36. 1932.
11. THOMAS, W. The feeding power of plants. Plant Phys., 5: 443–489. 1930.
12. THORNTON, H. G. The role of the young lucerne plant in determining the infection of the root by the nodule-forming bacteria. Proc. Roy. Soc., Ser. B, 104: 481–492. 1929.
13. ———————. The influence of the number of nodule bacteria applied to the seed upon nodule formation in legumes. Jour. Agr. Sci., 19: 373–381, Part II. 1929.

EVIDENCE OF FIELD HYBRIDIZATION IN BEANS[1]

W. W. MACKIE AND FRANCIS L. SMITH[2]

SINCE Johannsen's classical demonstration with the Princess bean in 1903 (8)[3], the fixity of pure lines from single selections has been largely taken for granted. The breeders of beans in both Europe and America who have resorted to artificial hybridization have, however, found that beans do not always remain fixed (9). Pearl and Surface (11), in Maine, working with yelloweye beans, found that it was necessary to grow the parental stocks in cages for several years to be certain of their purity. Emerson (2), in his studies of heredity in common bean hybrids in Nebraska, found cross-pollination which varied from 0 to 10%. Kristofferson (10) recorded cross-pollination amounting to 0.8% in snap beans and 1.42% in field beans. However, many varieties did not show evidence of cross-pollination even after being exposed for several years. Hardenburg (5) believes that hybridization in the bean fields of New York is of no commercial importance. Kooiman (9) cites a number of European and some American references to field hybridization in common beans. Without exception, the bumblebee is charged with the formation of the field crosses.

The evidence of field hybridization in California bean fields is spread over six species of beans grown in the state, namely, (a) common beans (*Phaseolus vulgaris*), (b) tepary beans (*P. acutifolius*), (c) blackeye cowpeas (*Vigna sinensis*), (d) *Multiflorus* or butter beans (*P. coccineus*), (e) small or baby lima (*P. lunatus* var. *Sieva*), and (f) large lima (*P. lunatus* var. *macrocarpa*).

Common beans were first introduced into California through the Spanish missions and have been grown without interruption ever since. Other species and varieties have been added from time to time (7). The conditions of climate and soil in California are adapted to a wide range of bean varieties. These advantages have placed her usually in the first rank in yield per acre and in the value of the crop, due to the superior prices of the lima beans, which are protected by a natural climatic monopoly. The situation is ideal, therefore, for observations on the occurrence of field hybridization.

On the coast, in regions south of Monterey Bay, Small Whites are grown almost exclusively in certain areas, like Salinas and Lompoc. In the fields near Salinas some years ago the Michigan Robust pea-bean was introduced. From this lot a field hybrid, apparently with California Pink, was isolated. The resulting hybrid plants presented a wide range in seed color (white, pink, brown, and black, with all intermediate grades), maturity, yield, and climatic adaptation. From the vicinity of Lompoc black and colored seeds have arisen in fields of Small Whites. These also have shown a wide range of characters. Among the colors, black and pink predominated. Pods

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[3] Figures in parenthesis refer to "Literature Cited," p. 909.

of normal types and blue pod types occur. The shape of this hybrid seed varies widely. From one of these arose the variety known as "Very Small Pink," the smallest seed of all varieties of common beans which we have observed.

At King City, in the interior portion of Salinas Valley, the California Pink bean is principally grown, owing to climatic adaptation. The Pink bean from this area commands a higher price due to superior quality. A request from farmers of this area to improve the yield and disease resistance of the Pink bean led to field selection of about 100 plants, all bearing Pink beans. These plants were then grown in plant-to-row tests in the following year at three places of widely different climates, *viz.*, Davis, Berkeley, and King City. Over 15% were found to be heterozygous for such factors as color, size, and shape of seed and disease resistance. Among the homozygous or fixed lots, a wide variation from the commercial ideal of the Pink bean appeared. In color, the variation ranged from brown to pale pink, lavender, and red. The size varied from an index of 26.3 to 42.8 when the normal Pink averaged about 33. (The index is the weight in grams of 100 average beans.) The shapes included cylindrical, oval, and very flat, and were widely different from the standard type for Pink beans. Resistance to Rhizoctonia, Fusarium dry rot, and charcoal rot varied as widely. In time of maturity the range extended from very early to very late. Some selections were so late that they failed to mature a crop. In yield, the lots varied from 580 pounds per acre for the poorest to 3,840 pounds per acre for the highest, with an average for the Pink checks of 1,890 pounds per acre. At King City the yields ranged from less than half that of the surrounding field to more than 50% greater, but the average yield for the selections averaged almost exactly the same as for the field from which they were taken. Only 30% of the selections were retained for further study, and certainly no more than five or six of them deserved further recognition as commercially fit. However, among the survivors a combination of high yields, satisfactory color in seed, and disease resistance superior to the present standard is assured.

Red Kidney beans grown in New York and Michigan are annually injured by various diseases, including anthracnose and a number of bacterial diseases. These apparently cannot exist under the climatic conditions of the Sacramento Valley, where this type of bean is principally grown. Sacramento seed is therefore in demand in New York. Seed from fields rogued for viny types and mosaic plants, when sent to eastern markets, showed off-types in the seed, which caused the rejection of certain lots. These off-type beans were selected out and planted. A wide range of fixed and heterozygous plants appeared at harvest. Of these 112 off-type selections, 22% proved heterozygous. Heterozygous lots for seed color comprised 14% and included red, pink, brown, black, white, and mottled. Judging by the characters represented in the seed and vines, the parents must have included Red Kidney, Mexican Red, Pinto, Large Whites, and other varieties. The viny types, which represented mainly field crosses between Red Kidney (a bush) and Mexican Red (a vine), comprised 9% of the heterozygous off-types. Size and shape of seed varied widely, the size indexes ranging from 29 to 71.4. Roguing did not remove completely these objectionable plants which usually bore off-type seed, because heterozygous plants could not always be distinguished from the regular Red Kidney bush, which is more like an upright vine than a typical bush in appearance. Many regular bushes, among them hybrid stocks, bore seed like Mexican Red and further complicated the purification by field roguing. This seed, although sent from the West, originally came from New York, hence part of the field crossing at least occurred under New York conditions, which indicates that this condition is worse in New York than Hardenburg (5) suspected. This contention is further supported by the appearance in these hybrids of bean types resembling the Magpie variety, grown only in New York. Continued roguing for 3 years has, however, so improved the purity of seed that it is now very difficult to find viny and off-type plants. Plant selections fixed for desirable qualities have been secured, as has been done with the California Pinks.

About 5 years ago (1930), a farmer in Sutter Basin found an early maturing vine in his Pink beans. The seed from this selection is now being grown in the Sacramento Valley under the name Early Pink. Plant selections from this lot have been tested for fixity and many plants heterozygous for size and color have been found. Off-type homozygous strains for these same factors render the variety as now composed undesirable by the trade, although its earliness and high yield appeal to the farmer.

MEASURES OF FIELD HYBRIDITY IN COMMON BEANS

In the plats at Berkeley 60,000 plants were grown in 1932, 8 of which proved to be field hybrids, or less than 0.013%. The F_1 hybrid of Robust, a white-seeded pea-bean, and California Pink is brown-seeded. In 1932 Robust and Pink were grown in adjacent rows. Seed from Robust was planted in 58 rows in 1933. Any brown-seeded plants would be F_1 hybrids and their number would be a measure of field hybridization between the two varieties the year before. Among 3,955 plants not a single brown-seeded one was found.

Both self color and mottled colors are dominant over white in the F_1. In 1933 pure white varieties were grown adjacent to colored ones. Seed from these white varieties were grown in 1934. All colored beans appearing among these were obviously field hybrids. The results obtained are shown in Table 1.

Field crossing in the 4,136 plants counted and observed was 50 plants, or 0.73%. These field hybrids are doubtless the result of crossing due to pollen carried from one row to another by adult thrips and appear to be a very reasonable measure of normal California field hybridization between adjacent varieties of common beans maturing at approximately the same time. That similar crossing occurs between individual plants within the variety may be assumed. Such hybrids may be detected by variations in the date of maturity, size and shape of seed, yield, disease resistance, and similar characters.

The tepary bean (*Phaseolus acutifolius*), an indigenous bean of the Arizona and Sonora regions found by Freeman (4) in cultivation by the Pueblo Indians of the Southwest, frequently crosses in the field, breaking up into all the usual color segregations found in the common bean. No field or artificial crossings have been secured between *P. acutifolius* and *P. vulgaris*, although such crosses have been attempted for 15 years.

TABLE 1.—*Percentage of natural hybridization in white-seeded beans, 1934.*

Variety	No. rows counted	Total no. plants	No. plants white	No. plants colored	% colored
Robust	31	2,143	2,130	13	0.61
Bluepod	9	483	477	6	1.24
Great Northern	2	102	102	0	0
Hungarian	1	77	77	0	0
Kotenashi	5	273	271	2	0.73
Large White	1	78	78	0	0
Michigan Pea	1	51	51	0	0
Small White	2	223	223	0	0
White Kidney	5	367	367	0	0
F_3 White, Pink x Robust	8	402	399	3	0.75
F_3 White, Pink x Large White	3	140	137	3	2.14
F_3 White, Pink x Great Northern	14	618	614	4	0.65
Total		4,957	4,926	31	0.63
Total from White F_3		1,160	1,150	10	0.86

Blackeyes (*Vigna sinensis*), although cowpeas, are classified commercially as beans. Artificial crosses between Blackeye and self-colored or mottled cowpeas yield black F_1 seed. Such seed has been recovered from a Blackeye field at the Riverside Citrus Station in a heterozygous condition. In Merced County, a field hybrid, evidently a cross between Iron and Blackeye, was found also in a heterozygous condition. Brabham seed likewise yielded hybrid seed in a heterozygous condition. At Modesto brown self-colored cowpeas have been found in Blackeyes, evidently having arisen from intercrosses among the Blackeye plants. This last type appears more frequently than the other forms mentioned.

Small or Baby limas (*P. lunatus* var. *Sieva*) throw commonly the so-called viny mutations or sports. One of these selected from the Henderson Bush gave rise to the Wilbur variety, a superior yielding viny type which has since remained fixed. Many of these viny "mutants" break up into vine and bush types, usually in a 3 to 1 ratio. Others break into bush and vine at different ratios, indicating different factors for vininess. In these heterozygous types Mendelian segregations occur in shattering, maturity, and stature of vine. Colored beans occur occasionally from these field crosses, usually represented by mottled brown and red seed. The small lima bean grown by the Hopi Indians of Arizona for centuries shows constant field crossing represented by a wide range of color variation from white to black, including many colored mottles. Heterozygosity is also expressed in plant stature, disease resistance, and maturity. From this stock selections were obtained for use in successfully breeding for the disease-resistant Hopi varieties now grown in areas where nematodes and Fusarium dry rot limit the production of Small lima beans.

Large lima beans (*P. lunatus* var. *macrocarpa*) include a large number of horticultural varieties, all of which have arisen from field selection. From fields of Large limas in Santa Barbara, where they were first introduced, a number of so-called "mutants" have been found, including willow-leaf, mottled, and red. Red beans rather frequently arise in Large limas, and although such red seed is all removed by hand picking, it arises again and again. Tests with this seed show it to be mainly in a heterozygous condition, usually breaking into red and white in a 3 to 1 ratio. A reverse ratio is also found, indicating the possibility of a dominant as well as a recessive white. This condition is being studied.

Fordhook, Burpee's Bush, Burpee's Improved Bush, and other Large lima varieties are grown by farmers for seedsmen under contract. The roguing of vines from these bush types is included in every contract. It is presumed that such viny types are rogues arising from admixtures during planting, threshing, and recleaning. Selections of such viny types tested in plant to row proved most of them to be field hybrids, which broke up into vine and bush types, usually at the rate of 3 vines to 1 bush. Wide variations from this ratio occurred, indicating the possibility of more than one factor for vininess. In some of these field hybrids the potato or round type of seed occurs, usually as a recessive which breeds true and may be borne by either bush or vine.

The evidence just presented includes types which are easily recognized, but the more important factors involved in these field hybrids which control quality, vigor, and hardiness in vines are usually overlooked. The plan started in 1930 for improving the Large lima bean included plant selection among the six best varieties found in the principal Large lima bean areas. These varieties were selected and re-selected for vines showing superiority in yield, early maturity, vigor, Fusarium resistance, and seed quality. Great variation was found, especially in size, color, and shape of seed. The size as measured by the index ranged from 44 to 177, or 400%, within one variety. This condition was found in all the older varieties, but to a lesser extent in those varieties of more recent origin, as might be expected. The Large lima bean is identified by radiations which extend fan-shaped from the hilum toward the dorsal edge. These radiations are darker colored than the rest of the seed coat. If they are wide and dark, the bean is given a dull, dingy, or gray cast, which detracts from its appearance and its marketing quality. A bright white bean with a slightly greenish case is desired. Yellowish tints in the seed-coat or a lack of brightness detract from marketable quality. Pits, or dimples, which are not found in Small limas, cause seed to look shrunken if too large. Twists or distortions of the seed are likewise undesirable. Transverse splitting of the seed coat due to weakness at the micropyle permits moisture and fungi to enter with corresponding damage to germination and quality. All of these characters are inherited and are therefore subject to control by breeding methods.

Among the 269 plant selections tested from 6 standard varieties of Large limas, over 14% were found to be heterozygous for one or more of the characters just outlined. More than 4% of fixed selections were found combining all the desirable characters sought.

Multiflorus or butter bean (*P. coccineus*) includes such varieties as the Scarlet Runner and Aztec and marks a strict departure from the other five species just considered because it must be insect cross-pollinated in order to fruit fully (6, 9). When colored and white varieties are placed adjacent, crossing invariably shows with the normal Mendelian segregations found in other beans.

INSECT POLLINATION

Field hybridization in beans is charged by practically all investigators to the bumblebee. Other insects, usually the honey bee, are added. To check this under California conditions, the senior author watched carefully for many hours daily bumblebees and honey bees, gathering nectar from bean flowers, especially the Large lima. In no instance did he observe either of these insects forcing open or tearing open the flowers of beans which had not already opened naturally. It is well known that all bean anthers spill pollen for a considerable period before the flowers open. Pollen grains begin to germinate 4 or 5 hours before pollination actually begins (12). The pollen tube enters the micropyle of the ovule within 8 or 10 hours after pollination occurs. The rapidity of these processes indicates that foreign pollen transplanted on the receptive stigma of the bean flower would be at a disadvantage in the race to enter the ovule in the process of fertilization. Unless the pollen tube of foreign pollen grows more vigorously, causing its nuclei to out-travel those of the flower's own pollen tube, it appears unlikely that bumblebees or honey bees could cause cross-pollination. That pollination from two sources at least may fertilize ovules in a single flower, we have demonstrated in artificial crosses. One such cross between a white-seeded female and a pink male yielded four seeds in the single pod. These seeds in the F_1 gave 3 colored and 1 white plants. The white seed arose, of course, from pollen spilled from the anthers of the white female flower at the time the artificial pollination was made. As we always pollinate immediately after emasculation, the two types of pollen had equal opportunity to fertilize the ovules.

Further studies of agents which might cause field cross-pollination showed the presence within all bean flowers in all bean areas of the state of a small but extremely active thrips, which was identified (3) as the western grass thrips (*Frankliniella occidentalis*). This thrips is not to be confused with the common bean thrips (*Hercothrips fasciatus*) which feeds on the leaves. The western grass thrips feeds on the flower parts, including the nectar and pollen, and is able to pierce the keel and attack the sexual parts. So numerous are these active little insects that several may be found inside a single bean flower. Competition causes them to drive one another out. Attached to their bent legs and to their bodies may be seen many pollen grains which are carried away with them in flight or otherwise. As vines are usually intertwined about one another, the thrips may readily carry pollen to the flowers of another vine. In contrast to the bees, the thrips usually enter a flower bud before the flower opens and can readily effect pollination before the anthers of the flower spill their pollen (1). That this early pollination may be effective we have proved repeatedly in artificial crossing when the anthers are removed green before any spilling of pollen occurs. The work of the western grass thrips (*F. occidentalis* (Pergande)) appears to us to be responsible for field hybridization in beans. This accounts for the large proportion of intervarietal crosses and the lesser number of crosses between varieties. These conditions in bean fields emphasize the need of planting and maintaining seed of strict varietal purity.

CONCLUSIONS

From the evidence presented, field hybridization in all six species of beans grown in California is of common occurrence. This cross-pollination usually occurs between plants adjacent to one another.

Field hybridization between vines within a variety has been shown to cause variation in size and color of seed and vigor and maturity of the vines, as in the case of the Salinas Pinks. Where disease resistance is a character of a variety, this quality may be disturbed or broken down, or in common terms, the variety may "run down". To prevent the running down of varieties by field hybridization, plant selections are made each year to verify the purity. The seed of such pure strains is made available for distribution through the pure seed organization, known as the Calapproved Seed Plan. This process must be continued if the purity of our bean varieties is to be preserved.

LITERATURE CITED

1. Annand, P. N. Thsyanoptera and the pollination of flowers. Amer. Nat., 60: 172–182. 1926.
2. Emerson, R. A. Heredity in bean hybrids. Nebr. Agr. Exp. Sta. Rpt., 17: 33–68. 1904.
3. Essig, E. O. Insects of Western North America. New York: Macmillan Company. 1926.
4. Freeman, G. F. Southwestern beans and teparies. Ariz. Agr. Exp. Sta. Bul. 68. 1912.
5. Hardenburg, E. V. The production and marketing of field beans. Cornell Univ. Agr. Exp. Sta. Ext. Bul. 98. 1924.
6. Hedrick, U. P., Tapley, W. T., Van Eseltine, G. P., and Enzie, W. D. Beans of New York. Geneva, N. Y.: New York State Agr. Exp. Sta. 1931.
7. Hendry, G. W. Bean culture in California. Cal. Agr. Exp. Sta. Bul. 294. 1918.
8. Johannsen, W. Ueber Erblichkeit in Populationen und in reinen Linien. Jena: G. Fischer. 1903.
9. Kooiman, H. N. Monograph on the genetics of Phaseolus. Bibliographica Genetica VIII: 295–413. 1931.
10. Kristofferson, K. B. Spontaneous crossing in the garden bean, *Phaseolus vulgaris*. Hereditas, 2: 395–400. 1921.
11. Pearl, Raymond, and Surface, Frank M. Studies on bean breeding: 1. Standard types of Yelloweye beans. Maine Agr. Exp. Sta. Bul. 239. 1915.
12. Weinstein, A. I. Cytological studies on *Phaseolus vulgaris*. Amer. Jour. Bot., 13: 245–263. 1926.

INHERITANCE OF EARLINESS AND LENGTH OF KERNEL IN RICE[1]

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THE primary purpose of this study was to determine if it is possible to isolate from crosses selections that are earlier and later than either parent, and also lines having different kernel lengths than those of the parents.

Crosses between short- and long-grain, short- and medium-grain, and medium- and long-grain varieties, varying in maturity, were made in 1929 at the Biggs Rice Field Station, Biggs, Calif., and the F_1 plants were grown there in 1930. In 1931 seed from the same F_1 plants was sown at the Biggs Rice Field Station, at the Rice Branch Experiment Station, Stuttgart, Ark., and at the Texas Agricultural Substation No. 4, Beaumont, Texas.

These three stations are located in areas having somewhat different environmental conditions, and information on the inheritance of earliness and kernel length from the same crosses, grown under such conditions, should be of interest.

During the growing season from May to September, inclusive, 1931, the average maximum temperature was slightly higher at Biggs, Calif., than at Beaumont, Texas, and Stuttgart, Ark. The average minimum temperature, however, was distinctly lower and the average mean temperature slightly lower at Biggs than at Stuttgart and Beaumont.

At Stuttgart the total precipitation for the 6-month period was 18.40 inches, at Beaumont 17.65 inches, and at Biggs 2.42 inches. The total evaporation was slightly higher at Biggs than at Stuttgart and distinctly higher than at Beaumont. The humidity of the atmosphere at Stuttgart and Beaumont, owing largely to the higher summer precipitation, was naturally higher than that at Biggs.

MATERIAL AND METHODS

The crosses Bozu x Edith, Bozu x Blue Rose, Colusa x Edith, and Colusa x Blue Rose were used in the study of the inheritance of earliness, and the crosses Butte x Edith, Caloro x Honduras, Colusa x Blue Rose, and Edith x Blue Rose were used in the study of the inheritance of kernel length.

Bozu, Colusa, Caloro, and Butte are short-grain varieties. Bozu matures very early, Colusa early, and Caloro and Butte are midseason varieties. Edith and Honduras are long-grain varieties that mature early in the southern States but late in California. Blue Rose is a medium-grain, late-maturing variety.

In the study of earliness the date of first heading of each F_2 plant was recorded.

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A plant was recorded as first heading as soon as one or more spikelets had emerged from the leaf sheath. First heading is hereafter referred to as headed.

In the study of the length and breadth (dorsiventral diameter) of seeds or kernels, mature panicles of each F_2 plant were collected and 10 kernels or seeds from the middle of representative panicles of each plant were measured.

EXPERIMENTAL DATA

INHERITANCE OF EARLINESS

The parents and F_1 plants were grown under like conditions at Biggs, Calif., in 1930. First heading of Bozu was on July 14, Colusa on August 13, Edith on September 2, and Blue Rose on September 4. The F_1 plants of Bozu x Edith and Bozu x Blue Rose first headed on August 5, Colusa x Edith on August 27, and Colusa x Blue Rose on August 29. In crosses in which Bozu was used the F_1 plants headed nearer the early than the late parent, whereas in crosses in which Colusa was used the F_1 plants headed nearer the late parent.

F_2 PLANTS

Seed from F_1 plants of the crosses Bozu x Edith, Bozu x Blue Rose, Colusa x Edith, and Colusa x Blue Rose was sown at Stuttgart, Ark., on May 11, at Beaumont, Tex., on April 24, and at Biggs, Calif., on April 7, 1931. The growing season at each station was satisfactory and the plants developed normally. The frequency distribution for date of first heading for the parents and F_2 plants of the crosses are shown in Table 1.

Bozu x Edith and Bozu x Blue Rose.—The segregation of the F_2 plants for earliness in the crosses Bozu x Edith and Bozu x Blue Rose was essentially the same at each station. Most of the F_2 plants in both crosses headed nearer the early than the late parent. At Stuttgart and Beaumont one or more F_2 plants in the cross Bozu x Edith headed later than the late parent, but none was as late as Blue Rose at Biggs. The heading period for the F_2 plants of the cross Bozu x Blue Rose did not extend beyond that of the parents. At each station the first heading of the F_2 plants covered a relatively long period and heading was relatively slow near the end of the heading period. There was a fairly high frequency class in the F_2 plants from both crosses at each station and seemingly minor variations for given dates which were probably due to the effects of variations in climatic conditions as well as to the action of genetic factors.

F_3 PROGENIES

A number of random F_2 families from the crosses Bozu x Edith, Bozu x Blue Rose, Colusa x Edith, and Colusa x Blue Rose were grown in F_3 at Stuttgart, Ark., in 1932. The number of F_2 families grown and results obtained are shown in Table 2. Of the 48 F_2 families from the cross Bozu x Edith four bred true, one being early, one late, and two intermediate. The remaining 44 families were segregating and intermediate in maturity. Of the 40 F_2 families from the cross Bozu x Blue Rose, 1 was as early as Bozu, 6 were early but not so early as Bozu, and the remaining 33 families were segregating and intermediate in maturity.

TABLE 1.—*Frequency distribution for date of first heading for the parents and F_2 plants of the crosses Bozu x Edith, Bozu x Blue Rose, Colusa x Edith, and Colusa x Blue Rose grown at Stuttgart, Ark., Beaumont, Texas, and Biggs, Calif., in 1931.*

Station, parents, and cross	Class centers (dates)																					Mean number days seeding to first heading
	June		July							August								September				
	23–26	27–30	1–4	5–8	9–12	13–16	17–20	21–24	25–28	29–1	2–5	6–9	10–13	14–17	18–21	22–25	26–29	30–2	3–6	7–10	11–14	
Stuttgart, Ark.																						
Bozu							4	19	3	1												73.24
Edith																21	11					106.63
F_2								17	30	89	171	90	43	25	25	3	4	4				87.20
Beaumont, Tex.																						
Bozu		9	9	3																		69.33
Edith												12	8	3								109.17
F_2			3	21	61	49	49	35	13	12	2	1	1	0	0	0	1					84.38
Biggs, Calif.*																						
Bozu	6–23 to 6–27																					72.00
Edith																			9–3 to 9–8			120.00
F_2		6	23	51	78	160	66	52	27	9	3	2	2	2	0	1						94.18
Stuttgart, Ark.																						
Bozu							4	19	3	1												73.24
Blue Rose																			35	10		118.37
F_2							6	28	36	55	81	42	26	26	30	19	10	6	2			88.28
Beaumont, Tex.																						
Bozu		9	9	3																		69.33
Blue Rose																7	8	2				125.94
F_2			37	48	43	27	13	26	26	22	5	13	4	1	0	5						85.07
Biggs, Calif.*																						
Bozu	6–23 to 6–27																					72.00
Blue Rose																			9–3 to 9–8			144.00
F_2	2	17	50	43	44	83	32	29	26	27	20	10	20	17	10	19	7					99.76
Stuttgart, Ark.																						
Colusa												6	7	7	6							95.50
Edith																21	11					106.63
F_2											12	19	64	55	53	9	31	88	86	36	5	106.75
Beaumont, Tex.																						
Colusa								2	9	5	1	1										95.17
Edith												12	8	3								109.17
F_2							3	10	53	33	24	18	20	41	37	44	19	4	1			109.36
Biggs, Calif.*																						
Colusa									7–26 to 8–12													106.00
Edith																			9–3 to 9–8			120.00
F_2							2	21	56	49	58	18	16	27	51	47	54	50	43	15	12	125.93
Stuttgart, Ark.																						
Colusa												6	7	7	6							95.50
Blue Rose																		35	10			118.37
F_2											2	6	23	27	29	5	12	106	97	31	1	110.88
Beaumont, Tex.																						
Colusa								2	9	5	1	1										95.17
Blue Rose																7	8	2				125.94
F_2								2	22	17	10	0	2	19	55	55	9					114.11
Biggs, Calif.*																						
Colusa									7–26 to 8–12													106.00
Blue Rose																			9–3 to 9–8			144.00
F_2									4	13	29	17	39	31	25	60	218	146	39			134.15

*At Biggs the first heading of individual parent plants was not recorded, so the range from first to last dates of heading is used.

TABLE 2.—*Segregation of F_3 progenies from the crosses Bozu x Edith, Bozu x Blue Rose, Colusa x Edith, and Colusa x Blue Rose for earliness at Stuttgart, Ark., in 1932.*

Cross and number F_2 families grown	Number plants that were			Deviation from		Remarks
	Early	Intermediate	Late	3:1 ratio and probable error	9:7 ratio and probable error	
Bozu x Edith						
1	29					Breeding true
2		46				Breeding true
1			30			Breeding true
44		1,222				Segregating, but not so late as late parent
Bozu x Blue Rose						
1	17					Breeding true
6	128					Breeding true, but not so early as early parent
33		1,123				Segregating, but not so late as late parent
Colusa x Edith						
17	322					Breeding true, but 1 late plant in 5 families and 2 in 1 family
6			87			Breeding true, but 1 early plant in 2 families
8	25		100	6.25±3.27		Segregating as expected
8	52		77		4.44±3.80	Segregating as expected
5	89		42			This unexpected segregation can not be explained
Colusa x Blue Rose						
13	346					Breeding true, but from 1 to 3 late plants in 5 families
9			231			Breeding true, but 1 early plant in 1 family
14	93		283	1.00±5.56		Segregating as expected
1	11		5			Unexpected segregation
Colusa x Blue Rose*						
1	33					Breeding true, but 4 plants slightly later than early parent
5			157			Breeding true
12	107		375	13.50±6.41		Segregating as expected

*Grown at Beaumont, Texas.

The frequency distribution of the F_2 plants for date of first heading and the data on the F_3 progenies indicate that Bozu differs in earliness from Edith and Blue Rose by more than two genetic factors, and the earliness of Bozu appears to be partially dominant.

Colusa x Edith.—A number of F_2 plants from the cross Colusa x Edith headed before the earliest Colusa plants and many also headed much later than the latest Edith plants (Table 1). By arbitrarily placing those F_2 plants that headed earlier and over the same period as Colusa in an early group and those that headed later than the latest of the Colusa plants in a late group the ratio at each station was about 9 late to 7 early plants. However, the fact that some plants headed earlier and others much later than either parent indicates that in addition to what appears to be the action of complementary factors, modifying factors also are involved in this case.

F_3 PROGENIES

Of the 44 F_2 families from the cross Colusa x Edith 17 were early (Table 2), 6 were late, 8 segregated in a ratio of 3 late to 1 early plant; 8 segregated in a ratio of 9 late to 7 early plants; and contrary to expectation, 5 families gave 89 early to 42 late plants. The latter results can not be explained satisfactorily. The few late plants in early families and the few early plants in late families may be due, in this and the following cross, to seed that floated in during irrigation, to unfavorable conditions for development, or to natural crossing in F_2. In the cross Colusa x Edith it appears that Colusa carries a factor for lateness which, in the presence of a late factor in Edith, delays the heading of some F_2 plants far beyond that of the Edith parent.

Colusa x Blue Rose.—At Beaumont and Biggs, F_2 plants from the cross Colusa x Blue Rose headed over about the same period as the parents. At Stuttgart, however, two F_2 plants headed earlier and 32 later than either parent. By arbitrarily classifying those F_2 plants that headed after the latest of the Colusa plants as late and all others as early, the ratio of late to early plants at Stuttgart and Beaumont was 3 : 1, but as stated, there were 2 F_2 plants that were earlier and 32 that were later than either parent at Stuttgart, and at Biggs the F_2 plants did not conform well to a simple Mendelian ratio.

Based on the arbitrary classification into two groups, at Stuttgart there were 252 late to 87 early plants; at Beaumont, 140 late to 51 early plants; and at Biggs, 519 late to 102 early plants. The total for Stuttgart and Beaumont was 392 late to 138 early plants and the deviation from a 3 : 1 ratio was 3.00 ± 6.72 plants, whereas at Biggs the deviation was extremely large.

F_3 PROGENIES

Of the 37 F_2 families from the cross Colusa x Blue Rose, grown in Arkansas (Table 2), 3 were early, 9 were late, 14 segregated in a ratio of 3 late to 1 early plant; and, contrary to expectation, 1 family gave 11 early to 5 late plants. Of the 18 F_2 families grown in Texas, 1 was early, 5 were late, and 12 segregated in a ratio of 3 late to 1 early plant.

The breeding behavior in the F_2 and F_3 generations of the cross

Colusa x Blue Rose indicates that the varieties differ in earliness by one main genetic factor and minor modifying factors.

In each of the four crosses used in the study of earliness the standard deviations and coefficients of variability of the F_2 plants were from 2 to 6 times that of the parents and each cross showed essentially the same type of segregation at the three stations. This indicates that in earliness the reaction of F_2 plants to an environment is determined largely by their genetic constitution.

KERNEL LENGTH AND BREADTH

One of the most constant quantitative characters of rice varieties is the length of seeds or kernels. The commercial rices grown in the United States may be classed according to length of kernel as short-grain, medium-grain, long-grain, and long-slender-grain. The F_2 segregation for kernel length in crosses between short- by long-grain varieties was studied in 1931 at Stuttgart Ark., Beaumont, Texas, and Biggs, Calif. At Biggs, F_2 segregation for kernel length also was studied in crosses between short- by medium- and long- by medium-grain varieties.

PARENTS AND F_1 PLANTS

The parent and F_1 plants were grown at Biggs in 1930. The average length of Butte and Caloro kernels was 5.0 and 5.2 mm and of Edith and Honduras 7.4 and 7.2 mm, respectively. The average length of F_1 kernels of the crosses Butte x Edith was 5.7 mm and of Caloro x Honduras 6 mm. The F_1 kernels were intermediate in length between the parents but nearer that of the short-grain parents. The average length of the F_1 kernels of the cross Colusa x Blue Rose was 5.7 mm, or the same as the average of the parents, namely, Colusa 5.3 mm and Blue Rose 6.1 mm. The average length of the F_1 kernels of the cross Edith x Blue Rose was 6.1 mm, the same as Blue Rose. Edith kernels averaged 7.4 mm in length. The F_1 seeds of the cross Lady Wright x Caloro averaged 8.11 mm in length and 3.56 mm in breadth. The average length of Caloro and of Lady Wright seeds was 7.12 and 9.26 mm, respectively.

F_2 PLANTS

The frequency distribution for length of kernels of the parents and F_2 plants of the crosses Butte x Edith, Caloro x Honduras, grown at the three stations, and Colusa x Blue Rose and Edith x Blue Rose grown at Biggs, Calif., in 1931 is shown in Table 3.

Butte x Edith and Caloro x Honduras.—The F_2 plants, from the crosses Butte x Edith and Caloro x Honduras, ranged in kernel length from short to long with no evidence of a distinct division into short-grain and long-grain groups, nor into short-, medium-, and long-grain groups. None of the F_2 plants from the cross Butte x Edith produced kernels that were quite so short as those of the shortest Butte plant nor quite so long as those of the longest Edith plant, except for one plant at Biggs. At each station the mean length of kernels of the F_2 plants was intermediate between that of the parents.

None of the F_2 plants from the cross Caloro x Honduras grown at Stuttgart produced kernels that were shorter or longer than those

TABLE 3.—*Frequency distribution for length of kernels of the parents and* F_2 *plants of the crosses Butte x Edith and Caloro x Honduras grown at Stuttgart, Ark., Beaumont, Texas, and Biggs, Calif., and Colusa x Blue Rose and Edith x Blue Rose grown at Biggs, Calif., in 1931.*

Station, parents, and cross	Class centers in millimeters																																		Mean length of kernels
	4.7	4.8	4.9	5.0	5.1	5.2	5.3	5.4	5.5	5.6	5.7	5.8	5.9	6.0	6.1	6.2	6.3	6.4	6.5	6.6	6.7	6.8	6.9	7.0	7.1	7.2	7.3	7.4	7.5	7.6	7.7	7.8	7.9	8.0	
Stuttgart, Ark.																																			
Butte			2	14	15	7	1	1																											5.10
Edith																						2	6	15	13	10	2	1							7.07
F_2							3	10	14	29	43	56	45	54	49	37	18	20	26	12	26	21	11	9	4	2									6.14
Beaumont, Tex.																																			
Butte	1	2	3	3	1																														4.91
Edith																							2	2	3	1	1	1							7.10
F_2					2	3	6	14	25	31	31	32	19	43	16	14	16	6	8	6	4	5	6	2	1	1									5.92
Biggs, Calif.																																			
Butte		1	0	4																															4.91
Edith																								5											7.03
F_2			1	2	8	9	12	21	35	28	32	34	33	12	14	24	8	11	4	7	2	3	1	1	1										5.80
Stuttgart, Ark.																																			
Caloro								5	12	11	3																								5.46
Honduras																											1	1	9	7	12	5	6	1	7.67
F_2								1	1	2	7	17	26	35	46	36	35	29	39	13	22	14	11	18	6	12	8	4	5	0	0	1	1		6.44
Beaumont, Tex.																																			
Caloro						1	2	5	2																										5.38
Honduras																										1	2	4	1	0	1	1			7.44
F_2					1	3	6	7	7	10	14	19	9	29	13	17	17	10	13	9	4	12	2	5	1	1	2	2							6.12
Biggs, Calif.																																			
Caloro				1	0	0	0	4																											5.31
Honduras																								1	0	4									7.11
F_2					1	0	3	3	12	9	17	19	23	22	19	9	7	7	4	7	7	8	4	2	0	2	1								6.05
Biggs, Calif.																																			
Colusa					2	0	3																												5.27
Blue Rose														1	0	4																			6.11
F_2					2	1	4	14	16	26	36	21	24	15	11	2	0	1																	5.72
Edith																								5											7.03
Blue Rose														1	0	4																			6.11
F_2											1	3	3	10	17	22	20	11	18	9	6	6	7	5	7	7	2	4	3						6.48

of the shortest and longest parent plants. At Beaumont, only one plant produced shorter kernels than those of the shortest Caloro plant and at Biggs one plant produced longer kernels than those of the longest Honduras plant. At each station the mean kernel length of the F_2 plants was intermediate between that of the parents but slightly nearer that of the short-grain Caloro parent.

Kernel length, as indicated by the segregation of the F_2 plants of the crosses Butte x Edith and Caloro x Honduras, appears to be due to the action of multiple factors.

In general, the kernels of the parents and F_2 plants were slightly longer at Stuttgart than they were at Beaumont, and slightly longer at Beaumont than they were at Biggs. The nature of the distribution of the F_2 plants for kernel length appears, however, to be essentially the same at the three stations, regardless of the differences in environmental conditions.

At Stuttgart the breadth of the kernels of the parents and F_2 plants of the crosses Butte x Edith and Caloro x Honduras was measured. The kernels of F_2 plants from the cross Butte x Edith ranged from 2.5 to 3.1 mm in breadth. Many exceeded those of Butte in breadth while others had less breadth than those of Edith. The mean breadth of the kernels of F_2 plants was, however, greater than that of Butte.

The breadth of F_2 kernels from the cross Caloro x Honduras ranged from 2.5 to 3.2 mm. Many F_2 plants produced kernels that had a larger breadth than the largest Caloro kernels and a few had less breadth than the smallest Honduras kernels. In other words, there was transgressive segregation of the F_2 plants for breadth of kernel, but the mean kernel breadth of the F_2 plants was intermediate between that of the parents but slightly nearer that of the Caloro parent which has kernels of larger breadth than those of Honduras.

Segregation of F_2 plants in the crosses Butte x Edith and Caloro x Honduras for breadth of kernel indicates that this character is probably controlled by multiple factors.

Colusa x Blue Rose and Edith x Blue Rose.—The kernels of F_2 plants of the cross Colusa x Blue Rose grown at Biggs, Calif., ranged in length from slightly shorter than those of Colusa to slightly longer than those of Blue Rose (Table 3). Most of the F_2 plants, however, produced kernels that were intermediate in length between those of the parents but slightly nearer that of Blue Rose. There was no indication of a distinct separation into groups having different kernel lengths.

The kernels of F_2 plants of the cross Edith x Blue Rose grown at Biggs ranged in length from shorter than those of Blue Rose to longer than those of Edith, but most of the F_2 plants were intermediate in kernel length between those of the parents but slightly nearer that of Blue Rose. There was no distinct segregation into medium-grain and long-grain groups nor into medium-grain, intermediate-grain, and long-grain groups. The fact that a number of F_2 plants produced kernels that were shorter than those of Blue Rose and other plants produced kernels that were longer than those of Edith indicates that kernel length in this cross was due to the action of multiple factors, although the genetic factors responsible for the medium-grain type appear to be partly dominant.

Kernel length in the crosses Colusa (short) and Edith (long) x Blue Rose (medium) appears to be controlled, as in the other crosses discussed, by multiple factors.

Lady Wright x Caloro.—The cross Lady Wright (long) x Caloro (short) was made at Biggs, Calif., in 1924. Caloro seeds averaged 7.12, Lady Wright 9.26, and those of F_1 plants 8.11 mm in length. The average length of the F_1 seeds was practically the same as that of the average of the parents. Seed of 200 F_2 plants ranged from 7.1 to 9.5 mm in length or over practically the entire range of the parents. Some F_2 plants produced seeds that were shorter and longer, respectively, than the average of those of the parent varieties. The average length of the seeds of F_2 plants was 8.08 mm, being somewhat nearer the average length of the seeds of Caloro than that of Lady Wright. There was no sharp division of the F_2 plants into short-, medium-, and long-grain groups as would be expected if seed length were due to one or two genetic factors. On the contrary, the data indicate that seed length in this cross is controlled by multiple factors.

In subsequent generations an attempt was made to establish true breeding lines having kernels shorter than those of Caloro, intermediate between those of Caloro and Lady Wright, and longer than those of Lady Wright. At the end of the crop year 1932 several selections appeared to be breeding true for kernel length. The range in kernel length of the true-breeding strains and the parents is shown in Table 4. The kernels of selection 48–1 undoubtedly are shorter and those of selections 48–6 and 130–2 are probably shorter than those of Caloro. Two selections have kernels of the same length as those of Caloro, that is, 5.2 mm. Several selections ranging in kernel length from 5.3 to 6.8 are intermediate between the parents. Three selections appear to have kernels slightly longer than those of Lady Wright, but the increase in length is so small that they probably are not significant.

The fact that true-breeding lines, varying in kernel length from 4.8 mm to 7.1 mm, have been isolated from this cross is good evidence that kernel length is due in this case to the action of multiple factors.

Since the progeny from crosses herein used in the study of kernel length have reacted in essentially the same way at the three stations, it seems fair to conclude that the parents used differ for length of kernels by more than two genetic factors.

This conclusion is supported by the fact that true-breeding lines have been isolated from the cross Lady Wright x Caloro and reciprocal that have kernels of various gradations in length between those of the parents. In selection work in the third and fourth generations of the other crosses studied, lines also have been observed with gradations in kernel length between those of the parents. In dealing with quantitative characters, such as length and breadth of kernels, it is to be expected that several genetic factors are likely to be involved.

TABLE 4.—*Length of kernels of apparently true-breeding lines isolated from the cross Lady Wright x Caloro and reciprocal grown at Biggs, Calif., in 1932.*

Variety or selection	Length of kernel in millimeters									
	4.8	5.0	5.2	5.3	5.4	5.8	6.2	6.8	7.0	7.1
48–1	+									
48–6		+								
130–2		+								
Caloro (parent)			+							
48–4			+							
48–10			+							
48–3				+						
20–1					+					
241B5–30						+				
241Bp 131–2						+				
241B21–3–1							+			
124–1								+		
Lady Wright (parent)									+	
1–1									+	
1–2									+	
61–3									+	
55–2										+
61–2										+
124–3										+

DISCUSSION

The nature of the F_2 segregation for earliness depends upon the varieties crossed. In the crosses Bozu x Edith and Bozu x Blue Rose the segregation for earliness herein reported indicates that this character is controlled by multiple factors and that the factors for earliness in Bozu are partially dominant. Others (3, 4, 5, 6, 9)[3] have reported that segregation for earliness in F_2 was apparently controlled by multiple factors.

In the crosses Colusa x Blue Rose and Colusa x Edith the F_2 plants, when arbitrarily divided into late and early groups on the assumption that all plants as early as the latest Colusa plant were early and all others late, gave about 3 late to 1 early and 9 late to 7 early plants, respectively. However, there were at Stuttgart, Ark., F_2 plants in the cross Colusa x Blue Rose that were earlier and later than either parent, and at Biggs, Calif., where climatic conditions are unfavorable for the development of late plants, the number of late plants was far in excess of those expected on a 3 late to 1 early basis. These facts indicate that earliness in this cross was probably determined by one main and also modifying factors.

At each station some F_2 plants from the cross Colusa x Edith headed earlier and others later than either parent. This transgressive segregation indicates that probably a number of factors are involved. However, on the basis of the arbitrary grouping mentioned above, the F_2 segregation agrees in general with a 9 late to 7 early ratio. This agreement does not mean that only complementary factors are involved in the segregation for this character but that the segregation

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[3] Figures in parenthesis refer to "Literature Cited", p. 920.

does appear to be dominated by complementary factors. A segregation in F_2 of 3 late to 1 early plant in rice crosses has been reported by other workers (1, 2, 6, 7).

The segregation of F_2 plants for length and breadth of kernels in crosses herein reported indicates that the varieties used differ by multiple factors. In the cross Lady Wright x Caloro and reciprocal, true-breeding lines varying in kernel length from shorter than the short parent to as long as the long parent have been isolated. This indicates that kernel length in this cross was controlled by multiple factors, and indications are that this also is true for the other crosses studied. Ramiah (10) reports that grain length and width are due to the action of multiple factors. On the contrary, Parnell (8) and van der Stok (11, 12) obtained F_2 ratios of 1 short to 2 intermediate to 1 long or long-slender grain plant.

SUMMARY

The segregation in F_2 for date of first heading in the crosses Bozu x Edith and Bozu x Blue Rose appeared to be controlled by multiple genetic factors; in the cross Colusa x Edith mainly by complementary genetic factors indicating a 9 late to 7 early ratio; and in the cross Colusa x Blue Rose largely by one main genetic factor giving about 3 late to 1 early plant.

In the F_2 populations of the crosses Butte x Edith, Caloro x Honduras (short- x long-grain), Lady Wright x Caloro (long- x short-grain), Colusa x Blue Rose (short- x medium-grain), and Edith x Blue Rose (long- x medium-grain) the length of kernel and the breadth of kernel in two crosses appeared to be controlled by multiple genetic factors.

The F_2 segregation at the three stations for date of first heading and kernel length was essentially the same regardless of the differences in climatic conditions. This indicates that under the conditions at the three stations where this work was done, the nature of the segregation of hybrid material is determined primarily by the genotypic constitution of the varieties used rather than by the climatic conditions under which the material is grown.

LITERATURE CITED

1. Bhide, R. K. Inheritance and correlation of certain characters in rice crosses. Poona Agr. Col. Mag., 18: 76–85. 1926.
2. Evans, G. Report of the Agricultural Department, Bengal, for 1921–22. Bengal Dept. Agr., Rpt. 1921–22. 1922.
3. Hoshino, Y. On the inheritance of the flowering time in peas and rice. Jour. Col. Agr., Tohoku Imp. Univ., 6: [229]–288. 1915.
4. Ikeno, S. A Text-book on Genetics. Tokyo. [In Japanese.] Ed. 3, 1918. Abstract in Bot. Abs., 2: 114–115. 1919.
5. Jones, J. W. Inheritance of earliness and other agronomic characters in rice. Jour. Agr. Res., 36: 581–601. 1928.
6. ————. Inheritance of characters in rice. Jour. Agr. Res., 47: 771–782. 1933.
7. Nomura, M., and Yamazaki, R. A study of the inheritance of the shooting time in rice-plant. Jap. Jour. Gen., 3: 112–130. 1925. [In Japanese. Abstract in Jap. Jour. Bot., 3: (18). 1926.]

8. Parnell, F. R., Ayyangar, G. N. R., Ramiah, K., and Ayyangar, C. R. S. The inheritance of characters in rice. Mem. Dept. Agr. India, Bot. Ser., 11: 185–208. 1922.
9. Ramiah, K. Inheritance of flowering duration in rice (*Oryza sativa*). Ind. Jour. Sci., 3: 377–410. 1933.
10. ———— and Parthasarathi, N. Inheritance of grain length in rice (*Oryza sativa*). Ind. Jour. Agr. Sci., 3: 808–819. 1933.
11. Stok, J. E. van der. Mededeelingen omtrent kruisings proven I, II. Teysmannia, 20: 735–738, 780–794. 1909.
12. ————. Onderzoekingen omtrent de bastaard-producten uit de kruisings der rijstvormen R 731 (moeder) en R 733 (vader). Teysmannia, 20: 652–667. 1909.

THE MAGNESIUM CONTENT OF GRASSES AND LEGUMES AND THE RATIOS BETWEEN THIS ELEMENT AND THE TOTAL CALCIUM, PHOSPHORUS, AND NITROGEN IN THESE PLANTS[1]

HARLEY A. DANIEL[2]

INFORMATION concerning the magnesium content of plants is very limited compared with the large amount of data that has been published on the chemical composition of various crops for many other common elements.

Latshaw and Miller (3)[3] studied the composition of five corn plants and found that the average magnesium content of the stems, grain, cobs, and roots was 0.179%. Miller (4) showed that cowpeas, soybeans, and andropogons contained 0.50, 0.70, and 0.19% of magnesium, respectively.

In a report on the influence of magnesium deficiency on phosphorus absorption of soybeans, Willis, Piland, and Gay (5) found a negative correlation of —.39 existing between CaO:MgO, and a positive correlation of .19 for $MgO:P_2O_5$ in these plants.

EXPERIMENTAL PROCEDURE

Composite samples of mature native grass were collected during 1930 to 1934, inclusive, from typical areas of native pasture land and from hay meadows grown on virgin soils in 35 counties of Oklahoma. The mature legumes were collected on the experiment station farms at Stillwater and Perkins, Oklahoma, at the time the plants were cut for hay.

The legume tops and roots were also collected on these farms each week when possible from April 1 to May 20, 1933. The roots of these plants were carefully removed from the soil by digging at the same time the tops were collected and washed several times with water to remove the soil.

The samples were dried at 105°C and were analyzed for total calcium, phosphorus, and nitrogen by official methods recommended by the Association of Official Agricultural Chemists. The filtrate was saved from the calcium determinations in each case and analyzed for total magnesium by Hibbard's (2) titration method in which the precipitate of magnesium ammonium phosphate was dissolved in 1/10 N standard acid and back titrated with a standard sodium hydroxide solution until neutral to methyl red.

RESULTS

MAGNESIUM CONTENT OF GRASSES AND LEGUMES

The magnesium content of 162 samples of mature grasses and legumes were studied and the data recorded in Table 1. According to these data, the average magnesium content of 19 different species of

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[2] Assistant Agronomist. The author wishes to express his appreciation to Randall Jones, student assistant, for the magnesium analyses, and to Dr. H. J. Harper, Professor of Soils, for collecting the samples analyzed in Table 2.

[3] Figures in parenthesis refer to "Literature Cited", p. 927.

TABLE I.—*The total magnesium content of mature grasses and legumes and the ratios between this element and the total calcium, phosphorus, and nitrogen content in these plants.*

Sample No.	Common name	Botanical name	No. of samples analyzed	Mg %	Ratios		
					Ca/Mg	P/Mg	N/Mg
		Grasses					
1	Little blue stem	*Andropogon scoparius*	30	0.138	1.84	0.46	3.95
2	Big blue stem	*Andropogon furcatus*	10	0.170	1.38	0.43	3.26
3	Big and little blue stem	*Andropogon furcatus* and *scoparius*	19	0.169	1.79	0.44	3.95
4	Short grass	*Bouteloua* and *Buchloe*	21	0.135	2.59	0.78	6.99
5	Grama grass	*Bouteloua gracilis*	8	0.145	2.16	0.69	6.43
6	Buffalo grass	*Bouchloe dactyloides*	9	0.148	1.92	0.73	5.76
7	Indian grass	*Sorghastrum nutans*	1	0.156	1.48	0.62	4.13
8	Triple-awn grass	*Aristida oligantha*	2	0.171	1.14	0.71	6.39
9	Diffused crab grass	*Leptoloma cognatum*	2	0.238	1.90	0.53	3.98
10	Broom sedge	*Andropogon virginicus*	3	0.102	2.35	0.82	5.98
11	Silver beard grass	*Andropogon torreanus*	2	0.202	1.62	0.56	3.55
12	Switch grass	*Panicum virgatum*	1	0.169	1.38	0.69	2.98
13	Love grass	*Eragrostis curtipedicellata*	1	0.059	5.46	2.42	22.06
14	———	*Sporobulus asper*	1	0.169	1.17	0.58	3.37
15	Salt grass	*Distichlis spicata*	1	0.184	1.73	0.70	5.17
16	Giant reed grass	*Calamovilfa longifolia*	1	0.130	1.10	0.96	3.92
17	Purple top	*Triodia flava*	1	0.189	1.37	0.65	6.08
18	Redtop	*Agrostis alba*	1	0.300	1.23	0.48	2.25
19	Sorghum	*Andropogon sorghum*	3	0.316	1.12	0.19	2.09
	Av. all grasses		117	0.156	1.86	0.56	4.68
		Legumes					
20	Cowpeas	*Vigna sinensis*	8	0.380	3.96	0.56	6.02
21	Velvet beans	*Stizolobium deeringianum*	4	0.329	4.19	0.66	6.59
22	Soybeans	*Soja max*	6	0.457	2.09	0.47	4.53
23	Peanut vines	*Arachis hypogaea*	6	1.024	2.00	0.09	—
24	Sweet clover	*Melilotus alba*	5	0.348	3.20	0.40	—
25	Alfalfa	*Medicago sativa*	16	0.345	5.34	0.53	7.69
	Av. all legumes		45	0.379	4.14	0.46	6.33*

*Average of 34 nitrogen samples.

TABLE 2.—*The magnesium content of legume tops and roots and the ratios between this element and the total calcium, phosphorus, and nitrogen in the plants at different stages of growth in 1933.*

Sample No.	Name of plant	Date collected	No. of samples analyzed	Tops				Roots			
				Mg %	Ratios			Mg %	Ratios		
					Ca/Mg	P/Mg	N/Mg		Ca/Mg	P/Mg	N/Mg
1	Austrian winter field pea*	Apr. 1	3	0.439	2.46	0.69	9.59	0.327	2.59	0.57	7.75
2	Hairy vetch†	Apr. 1	2	0.272	5.00	0.64	12.94	0.291	2.76	0.36	8.02
3	Sweet clover‡	Apr. 1	1	0.471	1.86	0.33	6.11	0.444	1.97	0.40	6.19
Av.		Apr. 1	6	0.389	2.93	0.61	9.66	0.334	2.50	0.47	7.49
4	Austrian winter field pea	Apr. 8	3	0.431	2.88	0.67	9.86	0.273	3.51	0.54	8.73
5	Hairy vetch	Apr. 8	2	0.253	4.90	0.86	12.89	0.224	4.04	0.65	10.04
6	Sweet clover	Apr. 8	1	0.404	2.50	0.49	7.00	0.374	2.39	0.53	7.25
Av.		Apr. 8	6	0.367	3.37	0.68	10.00	0.273	3.40	0.57	8.65
7	Austrian winter field pea	Apr. 15	3	0.385	3.44	0.79	11.28	0.230	3.64	0.71	10.90
8	Hairy vetch	Apr. 15	2	0.260	4.65	0.91	14.62	0.213	3.58	0.57	12.05
9	Sweet clover	Apr. 15	1	0.460	4.07	0.57	8.40	0.263	1.62	0.42	7.30
Av.		Apr. 15	6	0.355	3.60	0.77	11.52	0.230	3.23	0.61	10.58
10	Austrian winter field pea	Apr. 29	2	0.348	3.49	1.35	9.95	0.180	5.82	0.86	13.65
11	Hairy vetch	Apr. 29	2	0.255	5.15	0.97	10.65	0.199	4.24	0.56	11.55
12	Sweet clover	Apr. 29	1	0.381	4.07	0.42	6.75	0.359	1.25	0.24	7.02
Av		Apr. 29	5	0.317	4.15	0.86	9.42	0.223	3.78	0.56	10.80

13	Austrian winter field pea	May 5	3	0.343	3.11	0.68	9.79	0.223	4.07	0.43	10.32
14	Hairy vetch	May 5	2	0.265	3.07	0.71	11.30	0.220	4.47	0.41	9.45
15	Sweet clover	May 5	1	0.325	4.28	0.71	8.72	0.303	2.60	0.52	5.80
Av.		May 5	6	0.315	3.30	0.69	10.00	0.235	3.89	0.45	9.10
16	Austrian winter field pea	May 13	2	0.280	3.30	0.70	10.04	0.190	5.45	0.77	12.50
17	Hairy vetch	May 13	1	0.224	2.20	0.72	10.65	0.247	3.32	0.47	8.42
18	Sweet clover	May 13	6	0.322	3.28	0.51	7.99	0.326	1.73	0.35	5.92
Av.		May 13	9	0.302	3.18	0.57	8.75	2.287	2.43	0.42	7.28
19	Austrian winter field pea	May 20	1	0.269	3.58	0.78	10.92	0.169	5.45	0.72	13.32
20	Hairy vetch	May 20	1	0.224	4.20	0.93	12.40	0.179	3.96	0.52	10.00
Av.		May 20	2	0.246	3.88	0.85	11.62	0.173	4.70	0.62	11.72
	Av. all samples		40	0.334	3.38	0.69	9.95	0.262	3.12	0.50	8.68

Pisum arvense.
†*Vicia villosa.*
‡*Melilotus alva.*

grasses was 0.156%. These plants varied in percentages of this element from 0.059 to 0.316. The percentage of magnesium was higher in redtop grass and sorghum than in any of the native grasses. Love grass contained the lowest percentage of this element and sorghum the highest. These data show that the six different species of mature legumes averaged 0.379% magnesium. The velvet beans contained the lowest amount (0.329%) of this element and the peanut vines the highest (1.024%). Peanut vines were found to contain 2.24 times more magnesium than soybeans, the next highest plant. The legumes contained as an average 2.43 times as much magnesium as the grasses.

The data in Table 2 show the magnesium content of legume tops and roots at different stages of growth in 1933. Although there was a considerable variation in the individual plants, the average of the weekly samples showed that the percentage of magnesium decreased as the plant matured. With exception of the samples that were collected May 5 and May 13, the magnesium content of the roots of these plants also decreased as the plants matured. The percentage of this element in the tops varied from 0.246 to 0.389 and that in the roots from 0.173 to 0.334.

RATIOS BETWEEN PERCENTAGES OF MAGNESIUM AND TOTAL CALCIUM, PHOSPHORUS, AND NITROGEN IN PLANTS

The ratios between the percentages of magnesium and the total calcium, phosphorus, and nitrogen in the mature grasses and legumes are given in Table 1. The grasses averaged 1.86 times as much calcium, and 4.68 times as much nitrogen as magnesium, while they contained 1.79 times as much magnesium as phosphorus. The mature legumes were found to have a higher ratio of calcium and nitrogen to magnesium than the grasses. These plants averaged 4.14 times as much calcium and 6.33 times as much nitrogen as magnesium, and 3.72 times as much magnesium as phosphorus.

Due to the very low phosphorus content of peanut vines (1) and the very high magnesium content, these plants contain 11.1 times as much magnesium as phosphorus. All of the 19 species of grasses and the 6 different mature legumes studied contained more magnesium than phosphorus except love grass, and this plant contained 4.42 times as much phosphorus as magnesium. However, only one sample of this grass was analyzed. It is quite evident that the plants contained more calcium and nitrogen than magnesium and more magnesium than phosphorus, but very little relation seemed to exist between the content of magnesium and that of the other elements studied.

The rations between the magnesium and the total calcium, phosphorus, and nitrogen in the legume tops and roots are given in Table 2. The averages of these ratios were slightly higher in the tops than in the roots. The calcium-magnesium ratios in the tops varied from 1.86 to 5.15, the phosphorus-magnesium ratios from 0.33 to 1.35, and the nitrogen-magnesium ratios from 6.11 to 12.94. The ratios of these elements in the roots were found to vary similarly to those in the tops. The calcium-nitrogen ratios in the roots of the legume plants varied from 1.25 to 5.82, the phosphorus-magnesium ratios from 0.36 to 0.86, and the nitrogen-magnesium ratios from 5.80 to 13.65.

A careful study of the data given in Table 2 shows that there was very little relation between the chemical composition of the tops of plants and the same elements in the roots. The data seemed to indicate that the percentages of magnesium and nitrogen in the tops were more closely related to those in the roots than was the case with either calcium or phosphorus.

SUMMARY

The total magnesium content and the ratios between the total calcium, phosphorus, and nitrogen were studied in 162 mature plants and the tops and roots of 40 samples of legumes collected at different stages of growth.

The average magnesium content of the 19 species of mature grass was 0.156% and that of the 45 mature legumes 0.379%.

The grass varied in percentage of this element from 0.059 to 0.316 and the legumes from 0.329 to 1.024. Legumes were found to contain 2.43 times as much magnesium as the grasses. The data obtained showed that the magnesium content of legumes decreased as the plants matured.

The calcium-magnesium ratios varied in the mature grasses and legumes from 1.10 to 5.46, the phosphorus-magnesium ratios from 0.09 to 2.42, and the nitrogen-magnesium ratios from 2.09 to 22.06. The data recorded showed that the average of these ratios was slightly higher in the legume tops collected at different stages of growth than in the roots.

Very little relation was found to exist between the chemical composition of the tops of the plants and that of the roots.

LITERATURE CITED

1. Daniel, Harley A. The calcium, phosphorus, and nitrogen content of grasses and legumes and the relation of these elements in the plants. Jour. Amer. Soc. Agron., 26: 496–503. 1934.
2. Hibbard, P. L. Methods of chemical analyses. Selected for the use of students in plant nutrition. Berkeley, Calif. 1932.
3. Latshaw, W. L., and Miller, E. C. Elemental composition of the corn plant. Jour. Agr. Res., 27:845–859. 1924.
4. Miller, Edwin C. Plant Physiology. New York: McGraw-Hill Book Co. Ed. 1. 1931. (Page 234.)
5. Willis, L. G., Piland, J. R., and Gay, R. L. The influence of magnesium deficiency on phosphorus absorption by soybeans. Jour. Amer. Soc. Agron., 26:419–422. 1934.

THE RELATION BETWEEN BUSHEL WEIGHT AND MATURITY IN CORN[1]

WARREN H. LEONARD[2]

MATURITY is extremely important in corn grown under short-season conditions, such as those found in northern Colorado. It would be an advantage to the farmer to be able to detect immaturity in the seed he purchases through some simple test. Work conducted at the Colorado Experiment Station over a 3-year period indicates that the bushel-weight test may be used as an index of maturity in corn. This seems to be the case even though the bushel-weight determinations may be made several months after the corn is harvested.

LITERATURE REVIEW

There has been very little work published on the relation of bushel weight to maturity in corn, although bushel weight is regarded as a quality factor in the federal grain standards (1).[3] These standards require the following minimum bushel weights for grades 1 to 5, inclusive: 54, 53, 51, 48, and 44 pounds, respectively, per Winchester bushel. Lyon and Montgomery (2) early pointed out that deep-kerneled corn varieties grown under short-season conditions would produce comparatively deep but light-weight kernels. The bushel-weight requirements were made to discourage the sale of light-weight corn.

Robertson, *et al.* (3), reported that weight per measured bushel gave an indication of maturity in corn. They found that corn planted after May 10 gave progressively lower bushel weights after harvest as the season advanced. The corn from the later plantings was immature at the time of harvest. Their average bushel weights over a 4-year period were as follows for the April 20, May 1, May 10, May 20, May 30, and June 10 dates of planting: 57.8, 56.8, 55.2, 54.0, 51.6, and 45.5 pounds, respectively. Higher grain quality, as indicated by the bushel weight, characterized the corn planted at the earlier dates.

MATERIALS AND METHODS

Two field varieties of yellow dent corn, a Golden Glow selection and Pride of the North, were used in the test which was conducted over a 3-year period, 1931 to 1933. The first variety was grown all 3 years, while the second was used only in 1931 and 1933. Both varieties were planted each year between May 1 and 10, the optimum planting time for full-season corn at the Colorado Experiment Station. Golden Glow matured in the field each year on or about September 15, while Pride of the North matured a few days earlier.

Individual ears were harvested at five different dates, 10 days apart. These dates were August 22, September 1, September 11, September 21, and October 1. Sixty ears were harvested consecutively from a random place in the row for each

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[3] Figures in parenthesis refer to "Literature Cited," p 933.

variety on each date.[4] The field weights of the individual ears were taken, the ears tagged, and spread out on a floor where they remained until air-dry.

After being thoroughly dried, the ears were weighed again. Each ear was shelled and the bushel weight taken with a small grain kettle (Fig. 1). These determinations were usually made about 6 months after the harvest was completed. Three bushel-weight determinations were made on each ear and the average computed. It was necessary to discard some ears because they provided too little corn to fill the kettle, especially those harvested August 22. After the individual-ear bushel weights were taken, 100 kernels were counted for each ear, weighed, and then dried in a vacuum oven for 24 hours. The corn that remained was bulked for each variety at each date of harvest. The bushel weight was then determined on the composite sample with the standard bushel weight tester as prescribed in the Handbook of Official Grain Standards (4). This served as a check on the accuracy of the averages of the individual-ear determinations.

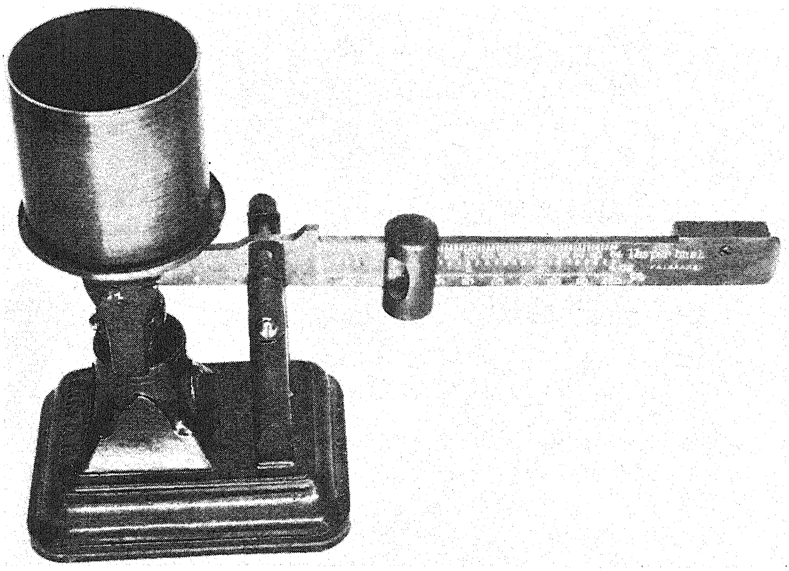

FIG. 1.— Small grain kettle used in making individual ear bushel-weight determinations. The drop from the bottom of the hopper to the top of the kettle was approximately 4 inches.

The mean bushel weight was determined for each variety for each date of harvest. Also, the percentage of moisture of ear corn on an air-dry basis and the mean weights per 100 kernels were computed. Standard errors were calculated in all cases. The correlation coefficient (5) was obtained for (a) bushel weight and percentage moisture of ear corn on an air-dry basis, (b) bushel weight and air-dry weight per 100 kernels, and (c) bushel weight and oven-dry weight per 100 kernels. The significance of the correlation coefficient was determined from Table V (A) given by Fisher (6).

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[4] Only 40 ears were harvested in 1931.

EXPERIMENTAL RESULTS

The data are presented only for the Golden Glow variety which was grown over a 3-year period. The results for Pride of the North, which was grown for 2 years, were similar to those obtained for Golden Glow and substantiated the conclusions drawn from the latter.

BUSHEL WEIGHT DETERMINATIONS

It will be seen from Table 1 that the individual-ear bushel weights progressively increased as the time of harvest was delayed, especially up to the point of field maturity which was reached about September 15. The bushel weight remained fairly constant after the corn was mature. The data show it to weigh over 54 pounds, the minimum requirement for U. S. No. 1 corn in the federal grain standards (1). In fact, the mature corn weighed over 56 pounds, the U. S. standard bushel weight for shelled corn. The Golden Glow strain harvested on September 1, which field observations showed to be in the soft dough stage at the time, averaged U. S. No. 2 corn for which the minimum weight is 53 pounds. The corn harvested August 22 obviously was immature at the time as shown by the fact that many ears were in the milk stage. The average bushel weight was below 50 pounds, placing this corn down to U. S. No. 4 for which the minimum requirement is 48 pounds. This corn proved to be chaffy when air-dry. The composite bushel weights, made from a mixture of corn from all ears, agree closely with the means determined from the individual ears.

TABLE 1.—*Bushel weights of Golden Glow corn harvested at 10-day intervals, 1931–33, inclusive*

Date harvested	Mean weight per measured bushel, lbs.			
	1931	1932	1933	Mean*
	Individual Ear Determinations			
Aug. 22	49.8±0.932	——†	47.0±0.852	48.40±0.631‡
Sept. 1	54.4±0.560	53.7±0.546	52.6±0.405	53.57±0.296
Sept. 11	58.0±0.350	56.2±0.476	57.1±0.405	57.10±0.239
Sept. 21	59.4±0.252	57.6±0.276	58.1±0.300	58.37±0.160
Oct. 1	59.3±0.325	58.4±0.281	59.4±0.224	59.03±0.162
	Standard Determination on Composite			
Aug. 22	49.1	45.4§	46.9	47.13
Sept. 1	54.5	54.2	53.5	54.07
Sept. 11	58.0	56.2	57.1	57.10
Sept. 21	58.8	57.9	58.5	58.40
Oct. 1	59.4	58.5	59.6	59.17

*Average of an average.

†Insufficient corn to make individual-ear bushel weight determinations with the size of grain kettle used.

‡Two-year average.

§Based on composite of all harvested ears.

WEIGHTS PER 100 KERNELS

The air-dry weights per 100 kernels increased for successive harvests up to the point of field maturity, i.e., September 15; thereafter, the air-dry weights remained practically constant. The data appear in Table 2. There was no significant gain in weights per 100 kernels between the September 21 and October 1 dates of harvest. The differences in bushel weights between these two dates also are slight. The oven-dry weights per 100 kernels show the same general trends. The whole kernels were dried for 24 hours in the vacuum oven in 1931 and in 1932, but it was later found that they were not reduced to a moisture-free basis in this length of time as determined by the Brown-Duval moisture tester (4). In 1933, a ground sample from each ear was dried in the vacuum oven for 24 hours.

TABLE 2.—*Weights per 100 kernels of Golden Glow corn harvested at 10-day intervals, 1931–33, inclusive.*

Date harvested	Mean weights per 100 kernels, grams			
	1931	1932	1933	Mean*
		Air-Dry Weight		
Aug. 22	16.84±0.611	14.03† ——	14.80±0.645	15.22 ——
Sept. 1	22.74±0.539	21.69±0.640	21.24±0.516	21.89±0.328
Sept. 11	28.95±0.530	25.41±0.640	27.87±0.531	27.41±0.329
Sept. 21	30.45±0.565	29.79±0.580	30.07±0.577	30.10±0.331
Oct. 1	30.45±0.637	30.34±0.540	32.07±0.589	30.95±0.341
		Oven-Dry Weight‡		
Aug. 22	15.78±0.584	——	13.15±0.697	14.47±0.455§
Sept. 1	21.14±0.504	20.13±0.620	19.82±0.480	20.36±0.311
Sept. 11	26.80±0.496	23.53±0.600	25.75±0.498	25.36±0.306
Sept. 21	28.56±0.616	27.85±0.520	27.79±0.531	28.07±0.322
Oct. 1	28.34±0.596	28.06±0.500	——	——

*Average of an average.

†Average of three determinations from composite shelled corn for this date.

‡Oven-dry weights computed from the moisture determinations made on 5-gram samples of ground corn from each ear on which an individual-ear bushel-weight determination was made.

§Two-year average.

CORRELATIONS WITH BUSHEL WEIGHT

The correlation coefficients between bushel weight and percentage of moisture in ear corn on an air-dry basis (Table 3) indicate a high significant negative correlation for immature corn. Previous data showed the corn to be mature about September 15. No significant correlations were obtained for corn harvested after maturity had been reached.

The correlation coefficients between bushel weight and air-dry weights per 100 kernels indicate a tendency for the correlation to be positive and significant in 1931 and 1932 for the August 22 and September 1 dates of harvest, but not significant in 1933. Thereafter, the results are erratic, with a tendency toward a low positive relationship which may be ascribable to chance in most instances.

When bushel weight was correlated with oven-dry weight per 100 kernels, the correlation coefficients were observed to be similar in behavior to those obtained for air-dry weights per 100 kernels.

TABLE 3.—*Correlations between bushel weight and other characters in Golden Glow corn, 1931–33, inclusive.*

Date harvested	No. ears	Bushel weight correlated with*			Expected r-value for P=0.05†
		% moisture ear corn air-dry basis	Air-dry weight per 100 kernels	Oven-dry weight per 100 kernels	
			1931		
Aug. 22....	17	—0.953	+0.742	+0.755	0.4821
Sept. 1....	38	—0.934	+0.497	+0.508	0.3206
Sept. 11...	38	—0.381	—0.048	—0.062	0.3206
Sept. 21...	40	—0.059	—0.045	—0.037	0.3125
Oct. 2.....	38	+0.321	+0.413	+0.418	0.3206
			1932		
Aug. 22....	—	———	———	———	———
Sept. 1....	33	—0.855	+0.649	+0.625	0.3444
Sept. 11...	31	—0.555	—0.011	—0.097	0.3557
Sept. 21...	54	—0.262	+0.310	+0.261	0.2686
Oct. 1.....	54	+0.129	+0.380	+0.181	0.2686
			1933		
Aug. 22....	16	—0.894	+0.325	+0.226	0.4973
Sept. 1....	46	—0.799	+0.214	+0.219	0.2909
Sept. 11...	51	—0.793	+0.332	+0.425	0.2761
Sept. 21...	54	———	+0.243	+0.255	0.2686
Oct. 1.....	52	———	+0.102	———	0.2732

*Obtained r-value. "r" equals correlation coefficient.

†From Table V (A) by Fisher (6). The r-value is obtained by interpolation where the degrees of freedom are not given exactly. The correlation is not considered significant when the probability that a correlation could exist with unrelated data is greater than P = 0.05.

CONCLUSIONS

The data presented indicate that bushel weight may be taken as an index of maturity. The bushel weights of Golden Glow, a yellow dent variety, progressively increased as it became more mature at the time of harvest. When harvested after maturity in the field, September 15, there was little change in bushel weight.

Mature Golden Glow corn had a bushel weight well over 54 pounds, the minimum requirement for U. S. No. 1 corn. The immature corn harvested August 22 would grade U. S. No. 4 on bushel weight.

The method of making individual-ear bushel weight determinations used in this test agreed with results obtained with the standard bushel weight tester.

The air-dry and oven-dry weights per 100 kernels increased markedly with successive dates of harvest until maturity was reached after which they remained practically constant.

The correlation coefficients between bushel weights and percentage moisture of ear corn on an air-dry basis indicate high significant negative correlations when the corn was harvested at immature stages. The correlation coefficients were low and lacked statistical significance for corn harvested after it had reached maturity in the field.

The correlation coefficients between bushel weights and air-dry weights per 100 kernels were somewhat erratic, although generally low and positive. The coefficients for the August 22 and September 1 dates of harvest were significant in 1931 and 1932, but not in 1933. The same general trends were observed for the correlation coefficients between bushel weights and oven-dry weights per 100 kernels.

Farmers in Colorado should suspect the maturity of Golden Glow corn when harvested if the bushel weight falls below 54 pounds, the minimum requirement for U. S. No. 1 corn under the federal grain standards.

The same general results were obtained over a 2-year period with Pride of the North, an earlier maturing variety.

LITERATURE CITED

1. ANONYMOUS. Official Grain Standards of the United States. B. A. E., U. S. D. A. Service and Regulatory Announcement No. 144. 1934.
2. LYON, T. L., and MONTGOMERY, E. G. Examining and Grading Grains. 1907. (Pages 40–41.)
3. ROBERTSON, D. W., *et al.* The date to plant corn in Colorado. Colo. Agr. Exp. Sta. Bul. 369. 1930.
4. BOERNER, E. G. Handbook of Official Grain Standards. B. A. E., U. S. D. A. 1929.
5. HAYES, H. K., and GARBER, R. J. Breeding Crop Plants. New York: McGraw-Hill Book Co. 1927.
6. FISHER, R. A. Statistical Methods for Research Workers. Edinburgh: Oliver & Boyd. Ed. 5. 1934.

DECOMPOSITION OF ORGANIC MATTER IN NORFOLK SAND: THE EFFECT UPON SOIL AND DRAINAGE WATER[1]

CHARLES E. BELL[2]

IN a previous publication (3)[3], studies were reported relative to the rate of decomposition of various organic materials when added to Norfolk sand. The rate of decomposition was measured by the amount of carbon dioxide evolved and quantity of nitrates found in the soil.

The present article deals with the effect of these organic materials on the soil as indicated by changes in reaction, loss through leaching, and exchangeable bases. The same soils used in previous experiments were used for obtaining data for this report. The dried organic materials were added to the soil at the rate of 1% by weight. All organic salts were added on a basis which would supply plant food equivalent to that contained in 100 pounds of a 4-8-4 commercial fertilizer per acre of 67 citrus trees, or an average of 1.5 pounds per tree. The data in this investigation, unless otherwise stated, were obtained after the soils had stood for a period of 1 year. For a complete description of the experiment the reader is referred to an earlier paper (3). The soil was treated as shown in Table 1.

The containers used in the experiment were ordinary 4-gallon, glazed, earthenware pots with a ¾-inch hole in the side near the bottom which facilitated drainage.

The materials were weighed out, thoroughly incorporated in the soil, and placed in the pots. There was a total of 72 pots, each treatment being made in quadruplicate. Two of these series (36 pots) were kept fallow while the other two (36 pots) were set with two seedlings of *Citrus* (*Citrus aurantium* L.). One fallow pot of each treatment (18 pots) was placed in the greenhouse under somewhat controlled temperature and moisture conditions, while the other fallow pot of each treatment (18 pots) was placed outside the greenhouse under ordinary atmospheric or field conditions. One pot of each treatment set to citrus seedlings was likewise placed in the greenhouse and one outside. By following this method it was possible to have two series of the soil treatments (as outlined above) in the greenhouse and two outside, one each of these series of 18 pots fallow and one series set with citrus seedlings. After all the seedlings were set, water was added to the pots in sufficient quantity to bring the moisture content up to 50% of the water-holding capacity of the virgin soil. This percentage of water (added as tap water) was maintained throughout the experiment in all pots kept in the greenhouse.

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[1] Part II of a thesis presented to the graduate faculty of the Iowa State College in partial fulfillment of the requirements for the degree of doctor of philosophy. Received for publication September 26, 1935.

[2] Associate Chemist, Department of Chemistry and Soils, Florida Agricultural Experiment Station, Gainesville, Fla. During the course of this investigation the author has discussed his problems with Drs. P. E. Brown and F. B. Smith of the Iowa State College and Drs. R. W. Ruprecht and R. M. Barnette of the Florida Agricultural Experiment Station. For their helpful suggestions and criticisms he is grateful.

[3] Figures in parenthesis refer to "Literature Cited", p. 945.

TABLE I.—*Quantities (grams) of material added to 40 pounds of air-dried soil in the various pots.*

Pot no.	Material added	Quantity added, grams	Pot no.	Material added	Quantity added, grams
1	Crotalaria	181.44	10	Cowpeas	181.44
2	Beggar-weed	181.44		$(NH_4)_2SO_4$	4.79
3	Natal grass	181.44	11	Manure	181.44
4	Cowpeas	181.44		$(NH_4)_2SO_4$	4.79
5	Manure	181.44	12	$(NH_4)_2SO_4$ (check)	4.79
6	Check, no treatment	——	13	Crotalaria*	181.44
7	Crotalaria	181.44	14	Beggar-weed*	181.44
	$(NH_4)_2SO_4$..........	4.79	15	Natal grass*	181.44
8	Beggar-weed	181.44	16	Cowpeas*	181.44
	$(NH_4)_2SO_4$	4.79	17	Manure*	181.44
9	Natal grass	181.44	18	Complete fertilizer only	
	$(NH_4)_2SO_4$	4.79		(check)	——

*Plus complete fertilizer
4.79 grams ammonium sulfate
13.31 grams superphosphate
2.49 grams potassium sulfate

EXPERIMENTAL

EFFECT OF SOIL TREATMENTS UPON pH OF NORFOLK SAND

The pH was determined by the quinhydrone method. The determinations were made at the beginning of the experiment just after the soil had been treated but before any water had been added to the pots, and again 122 and 346 days after treatment. The results are expressed by curves in Figs. 1 and 2.

The results obtained at the beginning of the experiment show that the mere presence of organic matter reduced the pH below that of the virgin soil, except in the case of manure. The application of ammonium sulfate or complete fertilizers alone or in combination with the organic materials further reduced the pH. The addition of an ammonium sulfate-manure combination reduced the pH below that of the virgin soil, but the reduction was not as great as when only sulfate of ammonia was added. The pH value of all the soils treated with the complete fertilizer was reduced even to a greater extent than in the case of the soils to which ammonium sulfate alone was added.

Cowpeas, which contained the greatest percentage of nitrogen of all the organics used, had an apparent greater power to lower the pH than any of the other organic materials. This was true under either greenhouse or field conditions. Natal grass tended to raise the pH in a majority of instances under all conditions after the initial determination. This would lead one to believe that the carbon-nitrogen relationship influenced the pH of the soil. Only in a few instances was the pH of the soil at the different dates found to be lower than at the beginning of the experiment. There was a greater tendency at 346 days for a higher pH under greenhouse than under field conditions, which was favored by the presence of citrus seedlings.

EFFECT OF SOIL TREATMENTS UPON RESIDUAL NITROGEN CONTENT OF NORFOLK SAND

At the end of the investigation the soils kept in the open were sampled and the total nitrogen determined by the Gunning-Hibbard method (1). The results were figured on a moisture-free basis.

Only the results from the soils kept in the open are given as they are more representative of actual field conditions than the soils kept in the greenhouse. An examination of the curves given in Fig. 3 shows that at the end of the year there was a slight increase of residual nitrogen in every case where the soils had been treated with organic matter alone over that in the corresponding check soils. The uncropped soils, where inorganic salts were added in addition to the organic matter, also showed a slight increase in nitrogen when compared with the respective check soils. Ammonium sulfate and complete fertilizer, when added alone, apparently slightly increased the nitrogen content over that of the virgin soil. When added with organic matter no marked increase of nitrogen was noted.

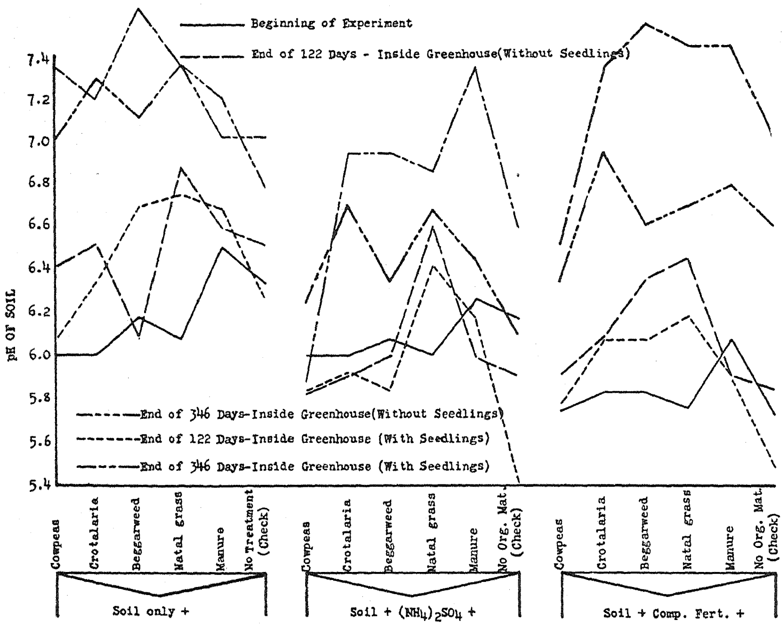

FIG. 1.—The effect of soil treatments upon the pH of Norfolk sand inside greenhouse.

EFFECT OF SOIL TREATMENTS UPON THE RESIDUAL ORGANIC MATTER OF NORFOLK SAND

As in the case of the residual nitrogen studies, only the soils under field conditions were used in this experiment. The method employed in determining the organic matter content of the soils was the loss on ignition. The results were figured on a moisture-free basis and represented by the curves in Fig. 4.

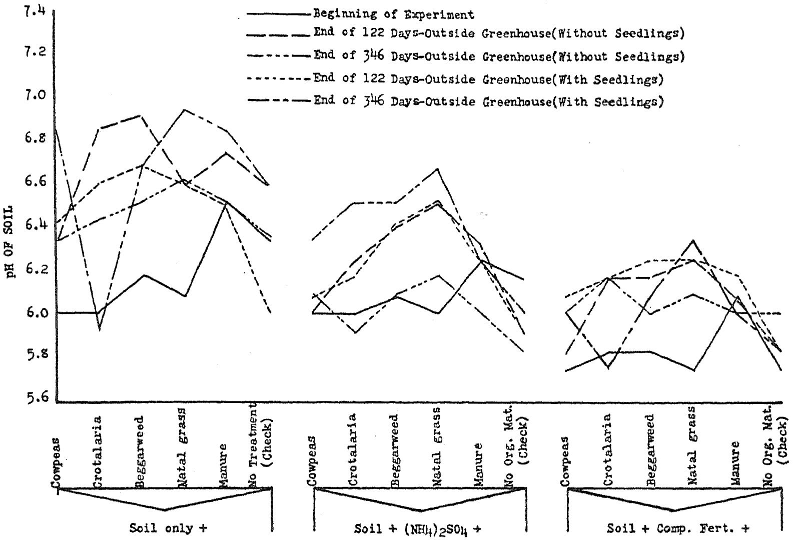

FIG. 2.—The effect of soil treatments upon the pH of Norfolk sand outside greenhouse.

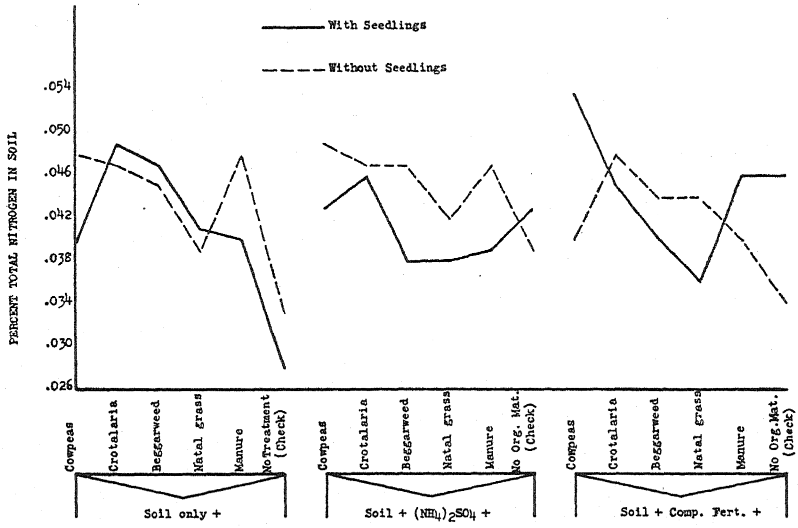

FIG. 3.—The effect of soil treatments upon the residual nitrogen content of Norfolk sand at end of 346 days.

It is evident that the addition of organic materials increased the amount of residual organic matter in the soil. The presence of citrus seedlings were favorable to a greater accumulation of organic matter in the soil except where complete fertilizer was added.

EFFECT OF SOIL TREATMENTS UPON TOTAL DRAINAGE AND NITROGEN LOST FROM NORFOLK SAND

The Gunning method (1) modified to include the nitrogen of nitrates was followed for the determination of nitrogen, 50.0 cc of drainage water being used for a sample.

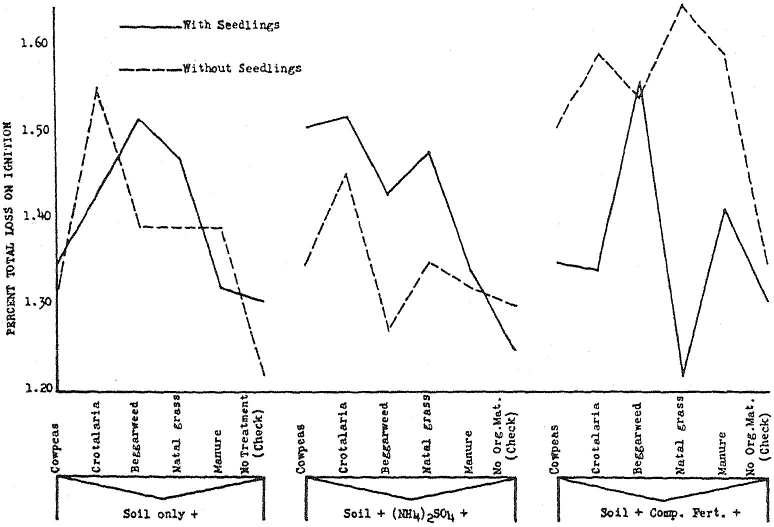

FIG. 4.—The effect of soil treatments upon the residual organic matter content of Norfolk sand at end of 346 days.

The curves presented in Fig. 5 give the total drainage from each soil during the period of the investigation and also the total nitrogen content of the drainage water expressed as grams lost per pot. As was to be expected, the curves show that the drainage from the fallow soils was greater than from those bearing seedlings. The addition of organic matter in the cropped soils reduced the amount of drainage water. There was, in general, an increase of drainage water from the fallow soils treated with organic matter. That there was a decreased loss of drainage in the cropped soil to which organic matter had been added, as against the checks of these series, may be explained by the increased growth of the seedlings in the presence of the organic matter. Judging from the amount of drainage from the fallow soils, the organic matter added at the beginning of the experiment had no effect upon the physical property of the soil in increasing its capacity for holding water at the end of 1 year.

There was a greater loss of total nitrogen from the fallow soils than from the cropped soils. This may have been due to a more concentrated solution, there being no seedlings present to utilize any of the soluble nitrogen. The presence of the organic matter, however, had an influence upon the nitrogen of the drainage water. With those organic materials which contained the higher percentages of nitrogen, there was the greatest loss of nitrogen. The loss of nitrogen in the presence of the various materials given in descending order was as follows: Crotalaria, cowpeas, beggarweed or manure, and Natal grass. There was a greater loss in the check soils than in the soils to which Natal grass was added which shows that of the materials used Natal grass was the only one that seemed to conserve nitrogen. This was probably due to the utilization of the nitrogen by the organisms which decomposed the Natal grass.

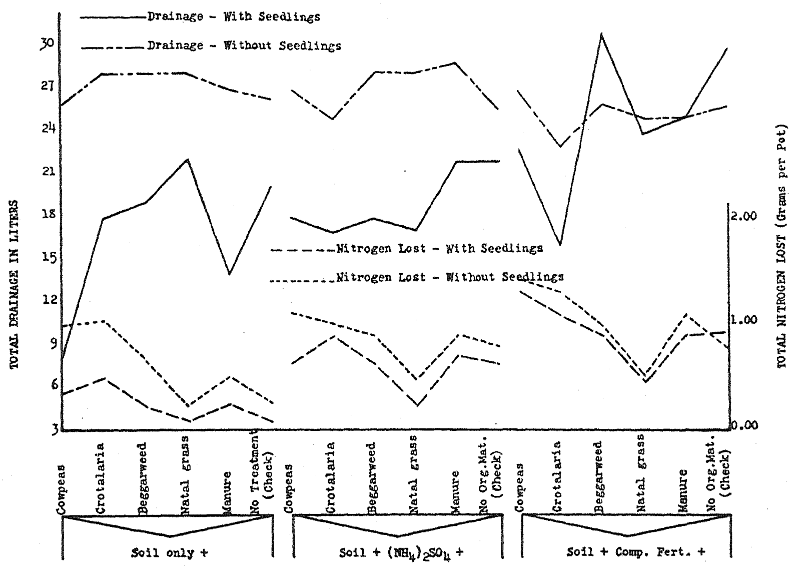

FIG. 5.—The effect of soil treatments upon the total drainage and nitrogen lost from Norfolk sand at end of 346 days.

EFFECT OF SOIL TREATMENTS UPON EXCHANGEABLE BASES (Ca, Mg, Na, AND K) OF NORFOLK SAND

The method employed in this work in the preparation of the base exchange solution was, with slight modifications, that used by Kelly and Brown (4) and as carried out in this laboratory was as follows: Fifty grams of the air-dried soil were placed in a 400-cc beaker. To this 350 cc of a normal NH_4Cl solution, heated to 90° C, were added and stirred at intervals until the solution had cooled to about room temperature; it was then filtered through a 15-cm filter. All the soil was then washed on the filter paper and the leaching continued, using cold normal NH_4Cl solution until 1000 cc had leached through the soil. Concentrated nitric acid was added to aliquots of this solution and evaporated to dryness to expel ammonium salts.

For the calcium, magnesium, sodium, and potassium the official methods (1) were followed. The results are expressed as milliequivalents of the cations per 100 grams of soil on a water-free basis.

In many soils the amount of water-soluble salts might be significant, but this was not the case in the Norfolk sand used in this investigation, so both the water-soluble and exchangeable forms were included as the exchangeable form. The data obtained in this experiment are presented in Table 2.

TABLE 2.—*The effect of soil treatment upon the exchangeable base content (Ca, Mg, Na, and K) of Norfolk sand.*

Soil treatment*	Milliequivalents per 100 grams soil									
	With seedlings					Without seedlings				
	Ca	Mg	Na	K	Total	Ca	Mg	Na	K	Total
Crotalaria	1.46	0.74	0.33	0.11	2.64	1.57	0.64	0.47	0.07	2.75
Beggarweed	1.64	0.85	0.39	0.09	2.97	1.68	0.74	0.54	0.06	3.02
Natal grass	1.78	0.95	0.37	0.12	3.22	1.71	0.74	0.46	0.11	3.02
Cowpeas	1.46	0.69	0.37	0.08	2.60	1.57	0.69	0.45	0.12	2.83
Manure	1.79	0.87	0.41	0.12	3.19	1.75	0.74	0.52	0.16	3.17
Soil only (check)	1.53	0.85	0.38	0.08	2.84	1.46	0.59	0.45	0.12	2.62
Crotalaria + $(NH_4)_2SO_4$	1.28	0.85	0.40	0.09	2.62	1.43	0.59	0.43	0.12	2.57
Beggarweed + $(NH_4)_2SO_4$	1.46	0.74	0.39	0.08	2.67	1.46	0.54	0.46	0.13	2.59
Natal grass + $(NH_4)_2SO_4$	1.46	0.69	0.42	0.09	2.66	1.46	0.59	0.44	0.12	2.61
Cowpeas + $(NH_4)_2SO_4$	1.28	0.69	0.41	0.08	2.46	1.57	0.49	0.47	0.12	2.65
Manure + $(NH_4)_2SO_4$	1.46	0.74	0.50	0.08	2.78	1.39	0.59	0.98	0.15	3.11
$(NH_4)_2SO_4$ (check)	1.21	0.69	0.56	0.11	2.57	1.25	0.49	0.63	0.12	2.49
Crotalaria + comp. fert.	1.18	0.54	0.27	0.05	2.04	1.61	0.59	0.52	0.12	2.84
Beggarweed + comp. fert.	1.21	0.49	0.28	0.04	2.02	1.71	0.64	0.50	0.12	2.97
Natal grass + comp. fert.	1.32	0.44	0.33	0.07	2.16	1.89	0.69	0.52	0.12	3.22
Cowpeas + comp. fert.	1.03	0.54	0.42	0.16	2.15	1.61	0.59	0.52	0.11	2.83
Manure + comp. fert.	1.21	0.44	0.32	0.17	2.14	1.79	0.64	0.38	0.11	2.92
Complete fertilizer (check)	1.14	0.39	0.39	0.20	2.12	1.46	0.54	0.48	0.12	2.60

*Soils analyzed at end of experiment.

A study of these data shows that the addition of organic matter tended to increase the exchangeable calcium and magnesium content in both fallow and cultivated soils when compared with the respective checks. The soils to which ammonium sulfate or the complete fertilizer were added, with few exceptions, contained less exchangeable calcium than those not treated with these materials. This fact may be due to the rise of acidity at the beginning of the experiment (Fig. 1) which probably caused the calcium to become soluble and more readily leached from the soil. The inconsistency noted in the case of the fallow soils to which the complete fertilizer was added was probably due to the absence of seedlings which would naturally utilize some of the calcium which was added in in the fertilizer. There was almost invariably more calcium, sodium, and potassium in the fallow soils. The fallow soils treated with the complete fertilizer were the only ones in which the total bases consistently exceeded those in the cropped soils.

From the individual treatments, it appears that the soils to which Natal grass or manure had been added contained, in most cases, more exchangeable calcium. The least amount of calcium was found in the soils treated with cowpeas and Crotalaria. When it is considered that of all the organic materials used the cowpeas and Crotalaria contained the largest amounts of nitrogen, it seems probable that this increased nitrogen was responsible for the loss of calcium. After oxidation to nitric acid it combined with the soil calcium and subsequently was leached from the soil.

Although the fallow soils uniformly contained more sodium and potassium than the cropped soils, the addition of organic matter failed to increase these constituents consistently. The only significant relationship of the divalent ions to the univalent is that the divalent ions are always in excess. This is in accord with results reported by Barnette and Hester (2).

EFFECT OF SOIL TREATMENT UPON BASES LOST IN DRAINAGE WATERS FROM NORFOLK SAND

One hundred cc of a composite sample of drainage water were used and calcium, magnesium, sodium, and potassium determined as in the case of the base exchange solution.

The data presented in Table 3 give the amounts of bases lost from Norfolk sand through drainage water. As in the case of nitrogen in the drainage water, more total bases were lost from the fallow soils. The loss both in the fallow and cropped soils, with few exceptions, was increased by the addition of organic matter. The addition of ammonium sulfate or a complete fertilizer, without organic matter, increased the loss of total bases to a greater extent than when the organic materials were used alone with the exception of the fallow check soil where ammonium sulfate alone was added. In this instance there was a greater total loss from the fallow soils treated with Crotalaria, beggarweed, or cowpeas alone than from the soil treated with ammonium sulfate alone. The combination of ammonium sulfate, or complete fertilizer, with the organic materials further increased this loss. The greatest loss occurred where the complete fertilizer was used with the organic materials. This was probably due to the soluble salts added in the complete fertilizer. These results would indicate that the loss of plant food from this soil through drainage water was dependent upon the quantity of soluble plant food present. Not only does the total quantity of plant food present in the soil influence the total amount lost, but the relationships among the various constituents making up the total may have an influence.

The loss of bases was apparently greater from those soils to which the greater quantity of nitrogen had been added. This would indicate that the nitrogen present in a soil influences the loss of bases from that soil. In the fallow soils, the loss from those soils to which Natal grass had been added was less than from the soils treated with any of the other organic materials, but greater than from the check soils. The cropped soils to which a combination of Natal grass and ammonium sulfate or Natal grass and the complete fertilizer was added lost less total bases than did the check soils of these series. The

TABLE 3.—*The effect of soil treatments upon the bases lost in drainage water from Norfolk sand.*

Soil treatment	Grams lost per pot									
	With seedlings					Without seedlings				
	CaO	MgO	Na_2O	K_2O	Total	CaO	MgO	Na_2O	K_2O	Total
Crotalaria	1.57	0.69	1.16	1.02	4.44	2.14	1.03	1.11	1.76	6.04
Beggarweed	1.02	0.47	0.73	0.80	3.02	1.85	0.94	1.07	1.46	5.32
Natal grass	1.19	0.54	1.01	0.99	3.73	0.81	0.56	1.12	1.26	3.75
Cowpeas	0.56	0.21	0.29	0.13	1.19	3.20	1.56	1.09	1.50	7.35
Manure	0.81	0.45	0.88	1.01	3.15	1.38	0.90	1.18	1.54	5.00
Soil only (check)	0.84	0.38	0.68	0.08	1.98	1.32	0.56	0.95	0.20	3.05
Crotalaria + $(NH_4)_2SO_4$	2.07	0.88	0.77	1.43	5.15	3.40	1.34	1.17	1.86	7.77
Beggarweed + $(NH_4)_2SO_4$	2.08	0.85	0.90	0.95	4.78	3.40	1.46	1.23	1.71	7.80
Natal grass + $(NH_4)_2SO_4$	1.91	0.81	0.84	0.91	4.47	2.34	1.11	1.49	1.30	6.24
Cowpeas + $(NH_4)_2SO_4$	3.40	1.44	0.90	1.28	7.02	3.34	1.53	1.12	1.32	7.31
Manure + $(NH_4)_2SO_4$	2.44	1.08	1.12	1.45	6.09	2.94	1.44	1.34	2.11	7.83
$(NH_4)_2SO_4$ (check)	3.11	0.86	0.97	0.22	5.16	3.05	0.97	0.81	0.30	5.13
Crotalaria + comp. fert	4.66	1.30	1.28	2.50	9.74	5.65	1.44	0.96	2.91	10.96
Beggarweed + comp. fert	4.90	1.55	1.15	2.05	9.65	5.94	1.46	1.36	2.44	11.20
Natal grass + comp. fert	4.93	1.44	0.46	2.05	8.88	4.65	1.35	1.21	2.31	9.52
Cowpeas + comp. fert	5.71	1.83	1.08	2.15	10.77	6.75	1.93	1.77	2.41	12.86
Manure + comp. fert	5.31	1.63	1.22	2.62	10.78	5.31	1.70	1.33	3.22	11.56
Complete fertilizer (check)	5.71	1.18	0.91	1.15	8.95	5.20	1.09	0.83	1.20	8.32

difference was very small, and hence it may be concluded that the addition of organic matter again failed to show any favorable influence for the conservation of the total plant food in these soils from loss through leaching.

When the individual bases are considered, it is apparent that the addition of ammonium sulfate only, or the complete fertilizer only, increased the loss of calcium over that lost from the untreated soil. The presence of organic matter tended to reduce this loss from the cultivated soils. With the other bases there was a greater loss, with few exceptions, from the soils containing organic matter than from the corresponding checks. In general, there was a greater loss of potassium than sodium or magnesium from the fallow soils to which organic matter alone or with the inorganic salts had been added. Similar results were obtained with the cropped soils to which ammonium sulfate, or the complete fertilizer, had been applied in combination with organic matter. The loss of magnesium from all the soils to which the complete fertilizer had been applied exceeded that of sodium.

EFFECT OF SOIL TREATMENTS UPON RELATION OF CALCIUM TO POTASSIUM IN DRAINAGE WATERS FROM NORFOLK SAND

Since Pierre (5), Ruprecht (6), and others found a correlation between the ratio of calcium to potassium in the soil solution, it seemed desirable to determine what this relationship was in the drainage waters in these tests. The data secured and presented in the form of curves in Fig. 6 were calculated from the results given in Table 3.

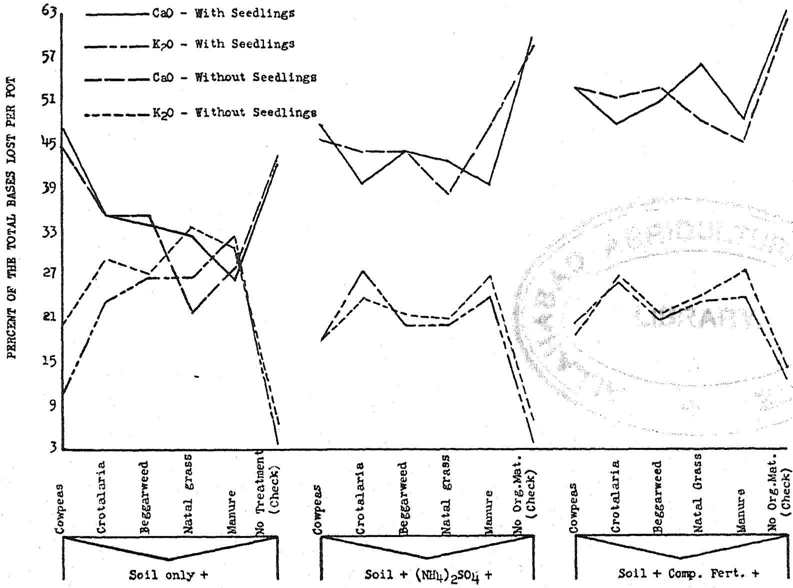

FIG 6.—The effect of soil treatments upon the calcium-potassium ratio in drainage waters from Norfolk sand.

These curves represent the percentage of calcium and potassium in the total bases leached.

It appears from these curves that the amount of divalent ion in the drainage water greatly exceeded the amount of the monovalent. The percentage of monovalent ion was greater in the drainage water from the fallow soil, however, than in that from the cropped soils, while the divalent ion varied considerably in the two cases. The application of ammonium sulfate, whether alone or in combination with organic matter, increased the percentage of calcium in the drainage in practically all cases. The complete fertilizer which contained both ammonium sulfate and calcium further increased this loss of calcium, which was expected.

These curves show a significant relationship between calcium and potassium. Where there was an increase of calcium there was almost always a decrease in potassium, even in the drainage waters from the soils to which complete fertilizer had been applied. The greatest amount of total calcium was lost from the soils which had been treated with the organic materials containing the greatest quantity of total nitrogen, but the proportion of calcium to potassium in the drainage waters from these soils was less. Apparently, as the quantity of calcium in the drainage water increased, that of potassium decreased.

SUMMARY AND CONCLUSIONS

Experiments were conducted to study the influence of various organic materials, inorganic fertilizers, and environmental conditions on the pH of the soil, on the amount of exchangeable bases present, and on the residual nitrogen and organic matter in Norfolk sand. Studies were also made relative to the quantity and composition of drainage waters from the soils variously treated. From data gathered calculations were made to determine the relation of calcium to potassium in the total bases in the drainage waters. The results of these studies may be summarized as follows:

1. The addition of freshly ground, dried organic matter to Norfolk sand reduced the pH of the soils at the beginning of the experiment below that of the virgin soil. The application of ammonium sulfate further reduced the pH and the soils treated with complete fertilizer were reduced in pH to a greater extent than in the case of the ammonnium sulfate treated soils. There was a gradual increase of the pH from the beginning to the end of the experiment.

2. The addition of the various organic materials caused a slight increase in the residual nitrogen in the soils after 1 year. The addition of inorganic nitrogenous fertilizer with these organic materials in cropped soils caused a slight loss of nitrogen when compared with those soils to which only organic matter had been applied. In those cropped soils to which inorganic nitrogenous fertilizers were added alone there was an increase in the nitrogen over that found in the untreated check.

3. The application of organic matter caused an increased residual organic matter content at the end of the experiment. There was apparently little difference in the kind of organic materials used in affecting this increase.

4. The application of organic matter to the soil apparently had little effect upon the amount of drainage water lost from Norfolk sand over a period of 1 year. More drainage water and total nitrogen were lost from the fallow than from the cropped soils and the quantity of nitrogen lost depended upon the amount added to the soil.

5. The addition of organic matter increased the exchangeable calcium and magnesium content in both the fallow and cropped soils over the respective checks. All the soils to which ammonium sulfate was added contained less exchangeable calcium than those soils not treated with this material. Additions of complete fertilizer to the soils kept fallow increased the exchangeable calcium. Apparently, the presence of nitrogen reduced the amount of exchangeable calcium in the soil. The fallow soils contained more exchangeable sodium and potassium than did the cropped soils.

6. As in the case of nitrogen, more total bases were lost through drainage from the fallow soils. The loss of total bases was increased by the addition of organic matter and applications of inorganic fertilizers increased their loss. The loss of bases was greatest from the soils to which the greater quantity of nitrogen was added. With the fallow soils, the loss of total bases from the soils to which Natal grass had been added was less than from soils treated with any of the other organic materials, but the difference was small. Even here the loss was greater than in the check soils, so that the addition of organic matter failed to show any favorable influence on the retentive power of Norfolk sand as determined in this investigation. The soils to which ammonium sulfate had been added showed the greatest loss of calcium, but the presence of organic matter tended to reduce this loss. The addition of organic matter seemed to cause a greater loss of sodium and potassium.

7. The divalent calcium ion occurred in greater amounts than the monovalent sodium or potassium in the soil as well as drainage water. This condition might have been due to a greater amount of the element calcium being present at the beginning of the experiment. The monovalent ions were of greater quantity in the drainage water from the fallow soils than in the water from the cropped soils, but the quantity of divalent calcium ion was about the same in the two cases. A greater quantity of the divalent magnesium ion was found in exchangeable form in the cropped soils, except where complete fertilizer was added. In the case of drainage waters this was reversed. There was a significant relationship between calcium and potassium in the drainage waters. As the proportion of calcium in the total bases increased, the proportion of potassium decreased.

LITERATURE CITED

1. ASSOCIATION OFFICIAL AGRICULTURAL CHEMISTS. Official and Tentative Methods of Analysis. Washington, D. C. Ed. 3. 1930.
2. BARNETTE, R. M., and HESTER, J. B. The influence of inorganic nitrogen compounds on the reaction and replaceable bases of Norfolk sand. Soil Science, 30:431–437. 1930.
3. BELL, CHAS. E. Rate of decomposition of organic matter in Norfolk sand as measured by the formation of carbon dioxide and nitrates. Jour. Agr. Res., 50:717–730. 1935.

4. KELLEY, WALTER P., and BROWN, S. MELVIN. Replaceable bases in soils. Cal. Agr. Exp. Sta. Tech. Paper 15. 1924.
5. PIERRE, W. H. Hydrogen-ion concentration, aluminum concentration in the soil solution, and percentage base saturation as factors affecting plant growth on acid soils. Soil Science, 31: 183–207. 1931.
6. RUPRECHT, R. W. Determination of the effect of green manures on composition of soils. Fla. Agr. Sta. Rpt., 1930: 60–61. 1930.

ERRATUM

TWO typographical errors occur in the article by Dr. H. H. Love in the October number of the JOURNAL, both on page 809. In the first formula on that page, r should be written as a subscript to σ (σ_r) rather than as an exponent. Also, in the sentence beginning "The formula for σ_2. . . .", the subscript of σ should be z and not 2.

AGRONOMIC AFFAIRS

REORGANIZATION OF AMERICAN SOIL SCIENTISTS

THE following statement has been prepared by Dr. Richard Bradfield on behalf of a joint committee representing the Soils Section of the American Society of Agronomy, the American Soil Survey Association, and the American Section of the International Society of Soil Science appointed at the annual meetings of these organizations in Washington in November, 1934. The recommendations made by this Committee will be considered in an open meeting at Chicago on the evening of December 4 next.

I. RECENT ACTIVITIES

The expansion of interests in the American Society of Agronomy, the American Soil Survey Association and the International Society of Soil Science within the last decade has resulted in considerable duplication of effort and some working at cross purposes. This has been realized by the members of these organizations and much thought has been given to possible solutions.

1. *In American Society of Agronomy.*—In 1930 the American Society of Agronomy appointed a committee to study plans for its reorganization. (Jour. Amer. Soc. Agron., 22: 1054. 1930.) This committee recommended in 1931 the reorganization of the Society on a sectional basis with a (1) Crops Section and a (2) Soils Section, each Section to be allowed to form "such subsections as it sees fit". (Jour. Amer. Soc. Agron., 23: 1032–34. 1931.) Provision was also made for two committees to formulate plans for the operation of each Section.

The committee for organizing the Soils Section (M. F. Miller, *Chairman*, M. F. Morgan, S. A. Waksman, and R. I. Throckmorton) submitted a report which was adopted and published in the Jour. Amer. Soc. Agron., 24: 1010–11, 1932. The new constitution is published in the Jour. Amer. Soc. Agron., 24: 839–841, 1932. Modifications made in the constitution before final adoption are to be found on page 1026 of the same volume of the JOURNAL.

The By-Laws of the Soils Section of the American Society of Agronomy provided (*loc. cit.*, page 1011) that "the Section shall function as the American Section of the International Society of Soil Science, but only those members paying the regular dues to the International Society shall have a vote in matters pertaining to it". After the adoption of this provision the objection was raised that the Soils Section of the American Society of Agronomy had no authority to set itself up "to function as the American Section of the International Society of Soil Science".

2. *In American Soil Survey Association.*—All the activities discussed thus far were in the Agronomy Society. At the meeting of the American Soil Survey Association in Chicago in 1931 "there was manifested considerable sentiment toward changing the name of the organization to the American Soil Science Association", as it was felt that the organization had outgrown its original name. Definite action was deferred. A questionnaire indicated that over 60% of the members were in favor of this change in name.

3. *Joint action.*—In view of these "sentiments" among the members of these three soil science organizations, a joint meeting of all men interested in soil science, whether a member of any, all, or none of the existing organizations, was held in Chicago at the time of the regular meetings of the American Soil Survey

Association and the American Society of Agronomy in November 1933. At this meeting a motion was passed providing that a committee consisting of (1) the Chairman and Secretary of the Soils Section of the American Society of Agronomy, (2) the President and Secretary of the American Soil Survey Association, and (3) the past President (Dr. J. G. Lipman) and the American Secretary of the International Society of Soil Science be requested to examine critically the constitution and by-laws of the Soils Section of the American Society of Agronomy and recommend such changes as seem desirable in order to provide:

1. For a single association of soil scientists, organized on a sectional basis similar to the International Society of Soil Science which shall function as the American Section of the International Society of Soil Science.

2. That the desirable features of the present associations be preserved in so far as it is possible.

3. That a copy of the recommendations of this joint committee be sent to every member of (1) the International Society of Soil Science in America, (2) the American Soil Survey Association, (3) the Soils Section of the American Society of Agronomy, and (4) to any other large organization of soil scientists in America which the committee desires to consider, not later than September 1934.

4. That the recommendations of this committee be considered first at a meeting to which all persons interested in soil science are invited to participate, such meeting to be held in Washington, D. C., at the time of the annual meeting of the American Soil Survey Association and the American Society of Agronomy.

5. That the final form of the recommendations adopted by this joint session be referred to the separate organizations for ratification.

In a report published in the Jour. Amer. Soc. Agron., 26: 806, 1934, this joint committee states that they were "unable to formulate any satisfactory plan or to agree on any form of a single association of soil scientists and accordingly no recommendation for the organization of such an association is presented". The committee did agree that it would be desirable to establish an American Section of the International Society of Soil Science and recommended a form of organization which was adopted in Washington in November, 1934. (See Jour. Amer. Soc. Agron., 27, 321, 1935, for details.) Thus, the committee instructed to draw up plans for bringing the soils scientists together in a single association were in the end responsible for the creation of an additional organization!

They recommended that a new committee be appointed to continue the effort to draw up plans for a "single association of soil scientists" in accordance with the motion passed at Chicago in 1933. This recommendation was approved and the following joint committee appointed:

A. L. Patrick and A. M. O'Neal,
Representing the American Soil Survey Assoc.
S. A. Waksman and M. F. Morgan,
Representing the International Society of Soil Science.
C. F. Shaw and R. Bradfield,
Representing the Soils Section of the American Society of Agronomy.

This communication is an effort by the above committee to find a solution to the problem.

II. THE NEED FOR A SINGLE SOIL SCIENCE ORGANIZATION

1. *Memberships overlap.*—The conditions which have led to the discussion and actions shown above have grown out of the over-lapping in membership and activities of the existing organizations. Detailed data on membership are ap-

pended. From these data it is apparent that almost one-third of the members of the Soils Section of the A. S. A.[1] are also members of the A. S. S. A. and almost half the members of the A. S. S. A. are also members of the Soils Section of the A. S. A. The over-lapping is actually even greater than these figures indicate because of the fact that most of the 125 men who are members of both organizations are active in both, while many who are members of only one seldom take any active part in either. The ease with which a meeting of one group can be transformed into the other, which in recent meetings has been largely a matter of changing presiding officers, is further evidence of how close these organizations have already grown together.

2. *Programs overlap.*—An analysis of the papers presented before the two groups shows that about half are of as much interest to one group as the other. (See table.) There has been a fine spirit of cooperation existing between the organizations the last few years but this cooperation has been due to the personal efforts of the officers. There is no provision in the by-laws of either organization to insure cooperation or to eliminate duplication. Each group normally proceeds independently of the other.

3. *Present system is unnecessarily complicated and expensive.*—It is evident that two organizations in which there is such an over-lapping of membership and interest would not function as efficiently nor as economically as a single well-coordinated organization. A single organization receiving the united support of the soil scientists of the country will have less overhead and hence will be able to devote a larger proportion of its funds and of the energy of its members to more productive efforts.

4. *Publications.*—Our publications can be improved, their circulation increased, and their prestige enhanced, both at home and abroad, if they are given the united support of the workers in this country. At present most of the papers on the A. S. S. A. program are printed in the annual BULLETIN. It contains however less than half of the soil science papers presented at the annual meetings. The rest are either scattered through several numbers of the JOURNAL of the A. S. A. or some other journal, or are not published at all. It would be a great convenience to have all the soil science papers published together in an annual volume of PROCEEDINGS.

The BULLETIN has a circulation of a little over 300. It is not as well known either at home or abroad as it should be. Papers published in it have not been abstracted by many of the abstract journals, consequently papers published in it have been frequently overlooked by other investigators.

If the soil scientists in the United States unite they could unquestionably make a success of a volume of PROCEEDINGS.

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[1] Hereafter, the following abbreviations will be used in this communication: A. S. A. for American Society of Agronomy; A. S. S. A. for American Soil Survey Association; I. S. S. S. for International Society of Soil and Science; and S. S. S. for the proposed new "Society of Soil Science".

Distribution of Memberships in the Three Soils Science Organizations in the United States, 1935

Total members (U. S.), A. S. A	768*
Total members (U. S.), A. S. S. A	270†
Total members (U. S.), I. S. S. S	114‡
Members of both A. S. A. and A. S. S. A	125
Members of A. S. A., A. S. S. A., and I. S. S. S	37
Members of A. S. A. and I. S. S. S	28
Members of A. S. S. A. and I. S. S. S	16
Total members I. S. S. S. in A. S. A	65
Total members I. S. S. S. in A. S. S. A	53
Members of I. S. S. S. who are members of neither A. S. A. or A. S. S. A	34

*Based on list received from P. E. Brown, Sec., Jan. 11, 1935.
† " " " " " A. L. Patrick, Sec., Feb. 4, 1935.
‡ " " " " " C. F. Shaw, Dec. 22, 1934.

PERCENTAGE OF TOTAL NUMBER OF SOILS MEN IN DIFFERENT ORGANIZATIONS

(Assuming one-half of A. S. A. members are interested primarily in soils.)

One-half American members of A. S. A	384
Members of A. S. S. A. who are not members of the A. S. A	145
Members of the I. S. S. S. who are members of neither A. S. A. nor A. S. S. A	34
Total number of soils men in all three present organizations	563
Percentage total in A. S. A	68.4
Percentage total in A. S. S. A	48.0
Percentage total in I. S. S. S	20.2
Percentage total in both A. S. A. and A. S. S. A	22.2
Percentage members Soils Section, A. S. A., in A. S. S. A	32.5
Percentage members A. S. S. A. in Soils Section of A. S. A	46.0
Percentage members I. S. S. S. in A. S. A	57.0

Distribution of Papers on Programs of A. S. A. and A. S. S. A. in 1933 and 1934

	1933		1934	
A. S. S. A	—	21*	—	41*
A. S. A	—	28	—	41
Biology Section	20	—	16	—
Fertility Section	4	—	10	—
Fertility and Chemistry Sections	4	—	7	—
Physics	—	—	8	—
Joint A. S. S. A. and A. S. A	—	21	—	14
Chemistry Section and A. S. S. A	6	—	5	—
Physics Section and A. S. S. A	6	—	—	—
Land Use and A. S. S. A	9	—	—	—
Fertility and Crops Section	—	—	9	—
Total Soils Papers	—	70	—	96
A. S. A. Crops Section (in addition to joint sessions)	—	22	—	23
General, A. S. S. A. and A. S. A	—	5	—	3
Total number papers on programs	—	97	—	122
Number papers published in A. S. S. A. Bulletin	—	33	—	40
Percentage soils papers published in A. S. S. A. Bulletin.	—	47	—	41.5

*Ten of the 21 papers in 1933 and 12 of 41 papers in 1934 were of equal interest and value to the Soils Section of the A. S. A.

III. HOW CAN THE DESIRED IMPROVEMENTS BE AFFECTED WITH THE LEAST DISTURBANCE TO PRESENT ARRANGEMENTS?

The almost unanimous approval given the resolution adopted at the joint meeting in Chicago in 1933 and again in Washington in 1934, clearly indicates that the great majority of soil scientists favor the formation of a single soil science society organized on a sectional basis similar to the I. S. S. S.

Several methods for bringing about such an organization have been proposed and discussed. Last year's Committee on Reorganization considered the possibility of forming an entirely new organization but in the end rejected the plan by a large majority. It has also been proposed that one or the other of the existing organizations should expand and become the American organization quite independently of the other. This plan would result in even more duplication and would have other undesirable consequences. Since there is so much overlapping in membership and interests at the present time, the Committee feels that the only logical solution is a merging of the two existing organizations (A. S. S. A. and the Soils Section of A. S. A.) to form a new Soil Science Society (S. S. S.).

The next question is, What relation shall the new S. S. S. have to the A. S. A.? All who have been approached with this question, whether members of the A. S. A. or not, feel that the close affiliation between the crops and soils groups which has existed in the A. S. A. should be continued. Soil science is now recognized throughout the world as a distinct science. Many feel for that reason that the new organization should be known as a Soil Science Society. For a reorganization committee to ignore this feeling is to invite failure. There seems to be no reason why a new Soil Science Society formed by fusing the A. S. S. A. and the Soils Section of the A. S. A. should not continue to function as the "Soils Division" of the A. S. A. In fact, such an arrangement should prove mutually advantageous.

Your Committee therefore recommends[2]:

1. THAT THE A. S. S. A. AND THE SOILS SECTION OF THE A. S. A. UNITE TO FORM A SINGLE ORGANIZATION WHICH SHALL BE CALLED
    (1) SOILS SCIENCE DIVISION OF THE A. S. A.
    (2) AMERICAN ASSOCIATION OF SOIL SCIENTISTS
    (3) AMERICAN SOCIETY OF SOIL SCIENCE (This group will be referred to hereafter as the S. S. S.)

THIS ORGANIZATION SHALL ALSO SERVE AS THE SOILS SCIENCE DIVISION OF THE A. S. A. IN ACCORDANCE WITH THE PROVISIONS OF THE REVISED CONSTITUTION OF THE A. S. A.

2. THAT IN VIEW OF THE WIDESPREAD INTEREST IN EROSION CONTROL AND OTHER TECHNICAL APPLICATIONS OF SOIL SCIENCE THAT A NEW SECTION, SECTION VI, BE FORMED TO FURTHER THE WORK OF THIS GROUP.
3. THAT THE VARIOUS FIELDS OF INTEREST IN BOTH ORGANIZATIONS BE ALLOCATED TO THE PROPER SECTION IN THE NEW ORGANIZATION AND THAT THIS DIVISION OF SUBJECT MATTER FOLLOW AS CLOSELY AS POSSIBLE THE SCHEME USED BY THE INTERNATIONAL SOCIETY OF SOIL SCIENCE.

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[2] All recommendations are printed in capital letters.

I. Physics, II. Chemistry, III. Biology, IV. Fertility, V. Morphology, and VI. Technology—or Conservation. (Including erosion control, drainage, irrigation, earth construction problems, highway foundations, etc.)

It is believed that each of these groups should be formed to further the specialized work in each field. It is realized at the same time that much of the work of these specialized groups is also of interest to those in other groups. This plan will provide opportunity for the various specialists to consider in their sectional meetings those problems of technic, etc., which are peculiar to that group alone. Subjects of interest to more than one group should be discussed before joint meetings of all sections concerned.

By arranging some of the specialized sectional meetings on the first day, the others on the last day, and the joint programs of more general interest in the middle of the week, members interested in the activities of one group only would be able to attend all the meetings of interest to them in two or three days, while those with more diversified interests could remain for the entire program. The aim should be to enable every one to hear as many as possible of the papers of interest to him with the least possible loss of time from his regular work.

The time required for the programs of the various sections will vary widely. No attempt should be made to standardize their length. Some sections may prefer to meet only every other year; others may find one or two half-day sessions ample, while others may require five or six.

OFFICERS OF THE S. S. S.—THE OFFICERS OF THE S. S. S. SHALL CONSIST OF A (1) PRESIDENT AND A (2) SECRETARY. THE SECRETARY SHALL BE ELECTED AT EACH ANNUAL MEETING TO SERVE UNTIL THE CLOSE OF THE NEXT, WHEN HE AUTOMATICALLY BECOMES PRESIDENT.

THE PRESIDENT SHALL PRESIDE AT THE MEETINGS OF THE S. S. S., SERVE AS CHAIRMAN OF ITS EXECUTIVE COMMITTEE, AND SHALL REPRESENT IT ON THE EXECUTIVE COMMITTEE OF THE A. S. A. HE SHALL SERVE AS A COORDINATOR OF THE VARIOUS SECTIONAL PROGRAMS AND, WITH THE ASSISTANCE OF THE EXECUTIVE COMMITTEE, ORGANIZE GENERAL SOIL SCIENCE PROGRAMS WHEN DESIRABLE.

IN ADDITION TO THE USUAL DUTIES OF HIS OFFICE, THE SECRETARY SHALL SERVE ALSO AS VICE-PRESIDENT AND SHALL SUCCEED TO THE PRESIDENCY THE FOLLOWING YEAR.

THE EXECUTIVE COMMITTEE OF THE S. S. S. SHALL CONSIST OF THE PRESIDENT AND SECRETARY AND THE CHAIRMAN OF EACH OF THE SECTIONS OR COMMISSIONS.

OFFICERS OF SECTIONS OR COMMISSIONS.—THE OFFICERS OF EACH SECTION SHALL BE (1) A CHAIRMAN AND (2) A SECRETARY. THE SECRETARY SHALL BE ELECTED AT EACH MEETING TO SERVE UNTIL THE CLOSE OF THE NEXT, WHEN HE AUTOMATICALLY BECOMES CHAIRMAN.

DUTIES OF OFFICERS OF SECTION OR COMMISSION. — THE CHAIRMAN SHALL (1) PRESIDE AT ALL MEETINGS, (2) BE RESPONSIBLE FOR THE ORGANIZATION OF THE PROGRAM OF HIS SECTION, AND (3) SERVE ON THE EXECUTIVE COMMITTEE OF THE S. S. S. THE SECRETARY SHALL (1) KEEP THE MINUTES OF THE ANNUAL BUSINESS MEETING AND REPORT SAME TO THE SECRETARY OF THE S. S. S., (2) COLLECT THE MANUSCRIPTS OF ALL PAPERS

READ BEFORE THE SECTION AND FORWARD THEM TO THE EDITOR FOR PUBLICATION IN THE PROCEEDINGS, (3) PRESIDE IN THE ABSENCE OF THE CHAIRMAN, AND (4) SUCCEED TO THE CHAIRMANSHIP OF THE SECTION.

PUBLICATIONS.—THE S. S. S. SHALL PUBLISH AN ANNUAL VOLUME OF PROCEEDINGS WHICH WILL INCLUDE ALL OF THE PAPERS PRESENTED AT ITS ANNUAL MEETING AND A REPORT OF ALL BUSINESS TRANSACTED. THIS VOLUME SHOULD BE PUBLISHED AS SOON AS POSSIBLE AFTER THE MEETING.

(The present committee represents the soil science groups only; the publication of crops papers presented at the annual meeting is a matter to be acted on by that group separately.)

This publication would take the place of the BULLETIN of the A. S. S. A. The BULLETIN has been paying its way on a $2.00 membership fee and a circulation of only 300. The JOURNAL of the A. S. A. has a circulation of about 1,500. With the united backing of all the soils men in the United States, it should be possible to build up a circulation of at least 1,000 for a volume of PROCEEDINGS. The advantages of having all the soil science papers published promptly after the meetings and together in one convenient volume is evident.

The editor of the JOURNAL of the A. S. A. states that he will probably publish 116 papers in 1935 of which 14 were soils papers presented at the annual meetings last fall. It is evident that the publication of these 14 papers in a volume of PROCEEDINGS would not seriously weaken the JOURNAL. In fact it would permit the JOURNAL to devote more of its space to contributed papers and would enable it to remove some of the present restrictions. The change should not greatly alter the subscription list of the JOURNAL as there are not many subscribing to the JOURNAL merely to get the 14 papers which, under the proposed plan, would be published in the PROCEEDINGS.

The title "Bulletin of the A. S. S. A." is misleading to one not acquainted with it. Its appeal is limited largely to those engaged in soil survey work.

There are probably more soil scientists in the United States than in any other country with the possible exception of the U. S. S. R. The PROCEEDINGS of the American Society of Soil Science published with the united backing of all American soil scientists would seem certain to receive more support both at home and abroad than the present BULLETIN which it would supercede.

Dues.—A cursory examination of the data cited above on membership in the present organizations indicates that a few are members of only one organization, many are members of two, and many others are members of at least three different soils organizations.

If it is to be acceptable to a group with such diversified interests the plan of reorganization, especially the system of dues, must be kept flexible. Opportunity for membership and limited participation should be provided at a relatively low sum. In order to encourage subscriptions and support for all of the activities and publications, a just system of club rates should be provided. Such a plan is now being used with success by the American Chemical Society, the Institute of Physics, and other scientific organizations.

The following scheme is proposed for adoption by the S. S. S. The exact cost of printing a volume of PROCEEDINGS is, of course, not known. It will depend on the number of volumes printed, the style of printing, etc. If it contains all the papers presented instead of the usual 40 to 50% published in the BULLETIN, the cost will be somewhat higher than that of the BULLETIN of the A. S. S. A., but should be considerably less than twice as much because of the enlarged circulation

The Committee recommends therefore:

THE ADOPTION OF AN ELECTIVE SYSTEM OF DUES AND SUBSCRIPTIONS WITH REDUCTIONS TO THOSE SUBSCRIBING FOR ONE OR MORE OF THE PUBLICATIONS. THE FOLLOWING SCHEDULE IS GIVEN AS AN ILLUSTRATION OF THE PRINCIPLE PROPOSED. THE EXACT CHARGES MAY HAVE TO BE CHANGED.

MEMBERSHIP IN S. S. S.	$1.00
MEMBERSHIP AND PROCEEDINGS	4.50
MEMBERSHIP AND JOURNAL	5.00
MEMBERSHIP, PROCEEDINGS, AND JOURNAL	9.00
MEMBERSHIP AND I. S. S. S. Amer. Sect. dues 50c; I. S. S. S. dues $5.00	5.50
MEMBERSHIP, PROCEEDINGS, JOURNAL, AND I. S. S. S.	14.00

Collection of Dues.—At the present time there is much "lost motion" and unnecessary expense in connection with the collection of dues, printing, and distribution of programs. In recent years, both the A. S. A. and the A. S. S. A. have printed the complete soils program of both organizations. This has been appreciated by the men who were members of only one organization and has been decidedly worth while. It has been an unnecessary expense, however, as 125 men received two programs. At the present, calls for dues are sent out as follows:

By the Secretary of the A. S. A.	$5.00
By the Secretary of the A. S. S. A.	2.00
By the Secretary of the I. S. S. S. (7.5 guilders)	5.00
By the Secretary of the Amer. Sect. I. S. S. S.	.50
	$12.50

A separate reply and a separate check is necessary for each. These are all small items, of course, but in the aggregate they would make a substantial contribution to our publication program.

We recommend therefore:

1. THAT THE SECRETARY-TREASURER OF THE AMERICAN SOCIETY OF AGRONOMY BE REQUESTED TO RECEIVE ALL DUES.
2. THAT THE SECRETARY-TREASURER OF THE AGRONOMY SOCIETY DISTRIBUTE EACH YEAR ABOUT ONE MONTH IN ADVANCE OF THE ANNUAL MEETING TO EACH MEMBER A PROGRAM LISTING *ALL* PAPERS TO BE PRESENTED AT THE ANNUAL MEETING TOGETHER WITH A CARD LISTING THE VARIOUS OPTIONS REGARDING PUBLICATIONS AND MEMBERSHIP WITH THE REQUEST THAT THE MEMBER CHECK THE PUBLICATIONS AND MEMBERSHIPS DESIRED AND MAIL A PAYMENT FOR SAME TO THE SECRETARY IN ADVANCE OF THE ANNUAL MEETING. THE SPECIAL RATES APPLY ONLY TO ADVANCED SUBSCRIPTIONS. MEMBERS FAILING TO RETURN THE CARD WITH PAYMENT FOR DUES AND SUBSCRIPTIONS BEFORE THE ANNUAL MEETING WOULD LOSE THE DISCOUNT ALLOWED IN THE CLUB RATES.

Advanced information regarding the approximate number of PROCEEDINGS desired will be necessary during the first few years of publication.

Bills for any expenditures made in connection with the duties of their office by the officers of the sections would be presented to the Secretary-Treasurer of the A. S. A. for payment.

IV. HOW WOULD THIS PROPOSED MERGER AFFECT EXISTING ORGANIZATIONS?

1. *American Soil Survey Association.*—This group would unite with the Soils Section of the A. S. A. to form the new American Society of Soil Science, or whatever name it decides to adopt. The various subjects discussed at its annual meeting would continue to be discussed before the appropriate section of the new organization. Papers dealing strictly with soil morphology, classification, and mapping would be presented before Section or Commission V, subjects of interest to both morphologists and chemists would be presented before joint meetings of these two groups. The program of Section V would no longer be crowded by the inclusion of chemistry or physics papers having little or nothing to do with morphology. As a member of the new S. S. S., however, every one would be entitled to join any or all of the six sections or commissions.

By establishing an affiliation with the A. S. A. the overhead costs of running the organization would be reduced. The collection of dues, printing and mailing of programs, etc., would be handled by the office of the Secretary-Treasurer of the A. S. A. The editing of the PROCEEDINGS could probably be done by the Editor of the JOURNAL of the A. S. A. The BULLETIN would be superceded by the PROCEEDINGS of the new Society with all the advantages pointed out above. While the name A. S. S. A. would disappear, the objectives for which it was created will unquestionably be furthered by this union with the other soil scientists of the country.

2. *Soils Section of the A. S. A.*—The existing sections would continue to function much as they have in the past. Closer cooperation with the morphology group would be assured. The formation of the new S. S. S. and the publication of the annual volume of PROCEEDINGS should greatly strengthen the work of this group.

3. *American Society of Agronomy.*—The new organization (S. S. S.) would serve as the Soil Science Division of the A. S. A. No change in the new constitution of the Society seems to be necessitated by the action proposed. The same close affiliation of soils and crops men which has existed in the past is preserved in the present arrangement. The proposed changes will undoubtedly strengthen the Soil Science Division and, as a consequence, the A. S. A.

Active membership in the Agronomy Society would be restricted to those paying $5.00 dues for membership and the JOURNAL. The members of the S. S. S. (all paying the $1.00 membership fee) would be entitled automatically to associate membership in the Society of Agronomy with the privileges specified in the constitution of (1) participating fully in all meetings, and (2) offering papers for publication in the JOURNAL.

To avoid confusion the committee would like to suggest that the TWO SECTIONS OF THE A. S. A. BE KNOWN AS THE CROPS SCIENCE DIVISION AND SOIL SCIENCE DIVISION, respectively. The term section can then be used for the groups within a Division.

4. *The American Section of the International Society of Soil Science.*—As now constituted, the American Section is a skeletal organization for the consideration of matters of interest to the American members. It will not organize programs and hence will not compete in this respect with other organizations. The constitution provides for officers to be elected annually. As there will often be little or no business to transact in off-congress years, it would seem more logical to make the terms of the officers of the American Section correspond to that of the Society as a whole, that is, 5 years or from one congress to the next. This

would mean selecting this fall officers to serve until the fall following the Congress in Germany in 1940.

It was suggested above that dues for all the soils groups be paid to the Secretary-Treasurer of the American Society of Agronomy. This would be but little additional work for his well-organized office and would eliminate the present duplication. In the schedule of dues proposed the rate for those who are members of the I. S. S. S. only would pay the American Section dues of 50c a year plus the amount due the Treasurer of the International Society. Members not wishing to join the American Section could of course send in their dues to Secretary Hissink directly. Members of the S. S. S. having already paid a membership fee would be exempted from this additional fee and would pay merely the amount required by the International Society. (This was reduced to 7.50 Dutch Guilders per year at the Oxford Congress.)

THIS IS A PRELIMINARY REPORT. IT IS SUBJECT TO MODIFICATION BEFORE, AT, AND AFTER THE CHICAGO MEETING IN DECEMBER. IF APPROVED IN PRINCIPLE, A NEW COMMITTEE SHOULD BE APPOINTED TO COMPLETE THE DETAILS.

NEWS ITEMS

On October 9 a special dinner was given by the members of the Agronomy Department and their wives at Iowa State College in honor of Dr. P. E. Brown, who celebrated his fiftieth birthday and who has completed twenty-five years of service in the Department. Dr. W. H. Stevenson, who was head of the Department during 22 years of the time Dr. Brown has been at Iowa State College, acted as toastmaster and paid high tribute to Dr. Brown and the efficient service he has rendered to the institution and to soil science and agronomy. Fifty-two people were in attendance.

Dr. L. A. Richards has joined the staff of Iowa State College where he will devote half of his time to the teaching of physics and half to research work in soil physics in the Agronomy Section of the Agricultural Experiment Station. Dr. Richards' research will deal primarily with problems relating to soil moisture and the erosivity of soils.

Roy E. Bennett has resigned his position as Research Assistant Professor of Soils at Iowa State College to accept a position with the Soil Conservation Service with headquarters at Bethany, Missouri.

Dr. W. W. Worzella was recently appointed Assistant in Plant Breeding, Purdue University. He will devote his time to research in the fundamental factors affecting the quality and winter hardiness in soft winter wheat.

Alfred J. Englehorn, Research Assistant Professor of Soils at Iowa State College, has been granted a leave of absence and is serving as Assistant Land Planning Specialist in the Land Planning Division of the Resettlement Administration with headquarters at Ames.

Dr. E. R. Henson, Associate Professor of Farm Crops at Iowa State College, is on leave of absence to assist with the program of the Resettlement Administration in Washington, D. C.

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GREEN PASTURES FOR THE PLANT BREEDER[1]

H. K. HAYES[2]

WHILE I have a broad general interest in many phases of agronomy, my own personal research has dealt chiefly with crop improvement including genetics of crop plants and the production of improved varieties with particular emphasis on disease resistance. I have decided, therefore, to discuss some of the accomplishments in plant breeding during the last 35 years, 26 of which I have spent in this field, and take a brief glimpse into the future.

In recent years some have maintained that one of the causes of over-production has been the development of high yielding varieties. This criticism of the work of plant breeders needs little discussion. The use of efficient varieties is one means of lowering the cost of production and efficiency of production certainly is an economic necessity if agriculture is to advance at the same rate as industry. Several writers have brought out the fact that industry supports a greater body of research in proportion to capital invested than does agriculture. Research that aims at more efficient production in agriculture must continue in the future as in the past.

If you have noted my title, "Green Pastures for the Plant Breeder", you may have concluded that this is only another instance of an agronomist gone wrong. You may have decided that the main theme of this talk would deal with some phase of that elusive game of golf that to some agronomists is an avocation. My own experience, however, leads to the conclusion that few agronomists are physically or temperamentally fitted to make that sort of green pastures more than a mild diversion. I have thought of "Green Pastures" in a symbolic sense. The successful plant breeder or other research worker must enjoy his occupation and to him it must be of outstanding importance. Green pastures for the plant breeder then refer to verdant fields for research and experimentation. In developing this thesis, I shall mention outstanding accomplishments in the field of plant breeding

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[1] Contribution from the Division of Agronomy and Plant Genetics, University of Minnesota, St. Paul, Minn. Paper No. 1391 of the Journal Series, Minnesota Agricultural Experiment Station. Presidential address delivered before the 28th annual meeting of the Society held in Chicago, Ill., December 5, 1935.

[2] Chief of the Division of Agronomy and Plant Genetics.

during the last 25 years, attempt an analysis of the main reasons for the success attained and discuss future possibilities.

The science of genetics as we know it today has been developed mainly during the period from 1900 to the present time. The great changes in plant breeding methods that have occurred during this period have resulted mainly from the application of plant genetic principles to the problems of the breeder. Plant breeding has become a science to the extent that plant genetics and other fundamental researches in plant sciences have been applied to the production of improved varieties. Dr. F. R. Immer tells of a talk with Dr. H. Nilsson-Ehle, the celebrated Swedish plant breeder, in which he asked Dr. Nilsson-Ehle if he thought plant breeding should be classed as a science or an art. The reply of this great leader was, "There is a great deal of art to plant breeding," and then he added emphatically, "*But more science.*"

This is not the time nor place to elucidate the many changes in genetic viewpoint that have occurred during the present century. It seems sufficient to emphasize the present conception that characters are the end result of the interaction of genetic factors and environment, that what is inherited is the manner of reaction under particular conditions and that most normal characters of crop plants are dependent on the interaction of a considerable number of genes. The art and science of plant breeding includes a determination of the most desirable characters of each particular crop after a study of available material including the wild relatives of the crop, the development of improved varieties containing these characters and at the same time discarding or eliminating undesirable characters. In accomplishing this end the plant breeder uses Mendel's Laws as a working method. Accomplishments in breeding disease resistant varieties of spring wheat and improved hybrid strains of corn will be used as illustrations.

BREEDING SPRING WHEAT RESISTANT TO STEM RUST

One of our main cooperative projects at Minnesota since 1915, in which agronomists, plant geneticists, cereal chemists and plant pathologists have cooperated, has been the development of a rust resistant variety of spring wheat of desirable agronomic type and of satisfactory milling and baking quality. This work is carried on thru cooperation between the Minnesota Experiment Station and the U. S. Dept. of Agriculture.

In these studies artificial epiphytotics of stem rust have been developed both under field conditions and in the greenhouse. The rust nursery in the field has consisted of several thousand rows yearly. During the early period of this study resistant vulgare wheats were unknown. Our present nursery has such a preponderance of strains of vulgare wheats highly resistant to stem rust that it is necessary to plant a considerable amount of susceptible host material in order that rust may develop sufficiently in the rust nursery so that a satisfactory spread of the disease may be made possible. The development of rust resistant strains has been accomplished by obtaining resistance from the Emmer group and the combining of this resistance with desirable agronomic characters of vulgare wheats thru a series of crosses and selections.

While at the present time much remains to be known about various phases of stem rust resistance in wheat, many problems have been solved. Some of the steps that have led to our present position may be mentioned.

1. The mode of inheritance of particular types of reaction to stem rust has been determined both in the greenhouse and field. The most important practical result of these studies is the conclusion that resistance to all forms of stem rust of wheat in the stage from heading to maturity may be dependent upon only a single or few genetic factors.
2. The pathogene causing the disease is composed of numerous forms, called physiologic forms, that can be differentiated by their manner of reaction on a series of wheat varieties and species known as differential hosts, this separation being made primarily on the basis of seedling reaction. Physiological resistance in the seedling stage is of such a nature that a wheat may be immune from one form of rust and susceptible to another. As an illustration, Kanred winter wheat and derivatives are immune from certain forms and highly susceptible to others. This knowledge explained the reason why Kanred winter wheat and derivatives may be highly resistant in one season and highly susceptible in another.
3. A knowledge of the causes of resistance has been of major importance. Thus the resistance of Kanred is physiological and acts only against particular rust forms. A second type of resistance in the field to many forms of rust as the plants approach maturity appears to be simply inherited. The exact cause of this type of resistance is unknown. Some have suggested that morphological and functional causes may be responsible. Others have given evidence indicating that this does not seem to be the explanation. Mature plant resistance is inherited, in some cases, in a simple Mendelian manner, especially where Hope and H44 are used as the resistant parents.
4. It has been learned also that extreme conditions of environment may cause an apparent breaking down of resistance to a particular disease. For example, a plant genotypically resistant to stem rust, if infected with loose smut, may be completely susceptible to rust. This conclusion seems essential in a logical viewpoint of disease resistance in plants. No one expects a potentially high yielding variety will give high yields under unfavorable conditions. Extreme conditions of environment may strongly modify reaction to disease by modifying the character which under normal conditions is responsible for the resistance to that particular disease.

Since 1915 at various times there have been periods when the development of spring wheats, satisfactory in other respects and carrying the desired stem rust resistance, looked to be an impossible task. A new variety named Thatcher, first released in the spring of 1934 and rather widely distributed in Minnesota, withstood the severe epidemic of 1935 remarkably well when other varieties such as Marquis and Ceres were severely injured. This variety has high yielding ability and appears desirable in milling and baking qualities. There is still room for improvement in several characters. Thatcher, however, appears to be a great step forward.

One of our leading plant breeders, Dr. Gaines of the Washington Agricultural Experiment Station, has made the statement that the study of disease resistance in plants and the development of resistant varieties has been one of the main reasons for the great popular interest in the science of genetics. My own illustration with spring wheat emphasizes the value of cooperation in research, the need of intensive study in order to solve underlying principles thus making possible the solution of complex problems and the development of the desired variety.

BREEDING IMPROVED HYBRIDS WITH CORN

Agronomists rather generally have a knowledge of what has been and is being accomplished with corn by modern methods of breeding. At any rate, hybrid corn is not a novelty today. The change in breeding methods came about by extensive and intensive research in which many members of this society have had a part. I shall not attempt an analysis of all major steps leading to our present position.

Comprehensive studies were undertaken about 1906 at the Connecticut Station by Dr. E. M. East and at Cold Spring Harbor by Dr. G. H. Shull. I had the privilege of starting my own work on corn improvement under Dr. East's direction in 1909. I was impressed with a statement of Dr. East's about this time that he started studies of self fertilization and crossing in corn to learn the physiology of inheritance in corn with the belief that this knowledge was a necessity in order to develop a logical plan of corn improvement. During my early studies a leading botanist asked me if we thought it would be possible to continue self fertilization, as he believed inbred lines of corn would run out eventually. The Mendelian explanation of hybrid vigor, and the results obtained from studies of self and cross-fertilization with many species, have been essential to an understanding of the physiology of inheritance with cross pollinated plants.

Jones' suggestion in 1917 for the use of double crosses did away with one of the early obstacles in the way of producing hybrid seed commercially. The studies of many investigators furnished a basis for a partial standardization of corn breeding technic. The work includes self fertilization and selection to obtain desirable inbred lines, top crosses to estimate the better combining lines, the test of single, three-way and double crosses of the most desirable lines, the selection and commercial propagation of the better lines and hybrids and the production of hybrid seed by commercial producers.

One of our large canners of sweet corn in Minnesota, the Minnesota Valley Canning Co., undertook several years ago the improvement of sweet corn by modern plant breeding methods under our general supervision. They expect next year to use hybrid seed for the greater part of their entire pack. Investigators in Iowa have adopted the policy of introducing hybrids only when they are 25 per cent superior to normal corn. Other states have reported marked increases in yield, ability to withstand lodging and in disease resistance of hybrids over normal varieties. The time is rapidly approaching when all progressive corn growers will use hybrid seed.

These results with hybrid corn have been brought about by intensive and extensive studies in corn improvement, carried out at many experiment stations and by private breeders. Many problems in corn breeding remain to be solved and new technics will be developed without doubt. The most important problem is to develop improved inbred lines. The reason for the remarkable combining ability of certain lines should be determined. There is need with corn as with other crops for more knowledge of the relative desirability of differential characters and the differences should be made known in terms of morphology, taxonomy, ecology, cytology, physiology, and pathology as well as in genetics.

These studies should answer such questions as the value of high or low leaf area in corn for different ecological regions, the relative importance of various types of root development, the causes of ability to withstand various types of lodging and of drought resistance. Questions of this nature are essential to the breeder and are of equal interest to other plant science workers.

It has been my purpose to give a glimpse of several plant breeding accomplishments and to emphasize the many questions that remain unsolved with crop plants such as corn and wheat that have received most extensive study. With these crops a good start has been made. The number of research problems yet unsolved furnishes future "green pastures" with crop plants for students of plant sciences.

IMPROVEMENT OF GRASSES

With many crop plants much less has been accomplished in crop improvement than with corn and wheat and with some crop plants, particularly the grasses, studies of improvement have not progressed very far. As one investigator stated the problem, the grass plants are in much the same condition as would result if all wheat varieties were mixed together and grown as a single crop without varietal separation. We should not overlook the fact that some countries of the world have made a good start in grass improvement, notably Wales, Sweden, and Canada. Our own country lags far behind altho there is much evidence of renewed interest in grasses and forage crops. A greater acreage in these classes of crops is recommended by agronomists and others for the future for many regions of United States in connection with the agricultural planning studies that have been made this last summer. Efficiency of production demands efficient varieties.

At present methods of breeding grasses and forage crops have not been standardized. The necessary information for such standardization is not available and certainly all grasses can not be handled by the same breeding method. There is a serious lack of such essential information as mode of pollination, extent of self sterility, and relative desirability in grasses of self fertility or sterility. It is evident that many grasses are mixtures of self fertile and self sterile lines. With red clover, for example, where formerly it was considered that cross fertilization was necessary to seed production, it is now known that highly self fertile lines can be selected. By genetic methods it should be easy to combine self fertility with other characters if that is desirable.

With timothy, some breeders in America have concluded that self fertilization and selection was a logical method of improvement. Several foreign workers state that timothy is highly self sterile and that self fertile and vital lines are so infrequent that self fertilization and selection are not logical methods of improvement.

At a conference on alfalfa improvement in Washington, there was a wide divergence of views regarding the extent to which self fertilization could be used as a logical tool in alfalfa improvement. The probable effects of self fertilization and selection with each of the grasses and forage crops should be made known.

All that was emphasized regarding the value of an intensive knowledge of differential characters with corn and wheat is of equal importance in grass and forage crop improvement. The returns from such intensive studies of grass and forage crop improvement would, I am sure, yield a handsome dividend, based on the cost of the research. Several trained investigators in nearly every state of our Union could find pleasant and profitable employment in grass and forage crop improvement. It is our privilege as agronomists to emphasize the importance of fundamental research as a means of developing efficiency in agriculture.

PROBLEMS IN THE BREEDING OF MILLET (*SETARIA ITALICA* (L.) BEAUV.)[1]

H. W. Li, C. J. Meng, and T. N. Liu[2]

MILLET is one of the few main food crops in North China. Its importance is only second to that of wheat, the leading crop of the region. The grain is used for human consumption as well as for feed for livestock. Millet straw furnishes the main forage for the livestock of the district. In the past, some selection work has been done in several experiment stations of North China; but so far as the writers are aware, no varieties are ready to distribute to farmers. Moreover, all the breeding work that has been carried out thus far follows methods used with small grains. It is urgent and necessary, therefore, to study some of the problems that one may encounter in millet breeding work. The senior author (1)[3] published a preliminary note on this work in 1934; but since then, additional work has been carried out and the results are now reported in this paper.

ANTHESIS

Some knowledge of the blooming habits of a species is necessary before artificial hybridization can be carried out successfully. The detailed description of the opening of the millet flower has been reported (1); however, a brief summary of the process is given here.

MANNER OF BLOOMING

Each spikelet of millet has two flowers, the lower one sterile, the upper one with both stamens and pistil. Under normal conditions, blooming starts about 5 days after the head emerges from the boot. The flowers open gradually. As the glumes begin to spread, the anthers and pistil push their way out (Fig. 1), although sometimes they come out simultaneously. As a general rule, the anthers begin to dehisce after they are fully extruded. This is of particular interest in connection with the technic of hybridization as it will be described later. After dehiscence, the flower begins to close up, leaving only the shrivelled anthers and the tip of the stigma outside. The average time required for the opening and closing of the flower is 70 minutes (average of five varieties).

The order of blooming of the spikelets in the head is very regular, usually starting from the top of the head and proceeding toward the base. For the side branches, the order is the same as for the whole head. It usually requires from 12 to 15 days for the whole head to finish blooming, although of course, this will vary with the environment and the variety concerned.

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[1] Contribution from the College of Agriculture, Honan University, Kaifeng, Honan, China. Received for publication July 2, 1935.

[2] Professor and Associates in Plant Breeding, respectively. The authors are deeply indebted to Dr. H. H. Love of Cornell University for many helpful criticisms and suggestions regarding this paper.

[3] Figures in parenthesis refer to "Literature Cited", p. 970.

TIME OF DAY OF BLOOMING

Rangaswami Ayyangar, *et al.* (2) reported that there is a definite periodicity in the opening of the flowers during the 24 hours, with maxima between 10 p. m. and midnight and between 6 a. m. and 8 a. m. In the hot weather the two periods are nearly equal in intensity, but in cold weather, the second period is only half the intensity of the first.

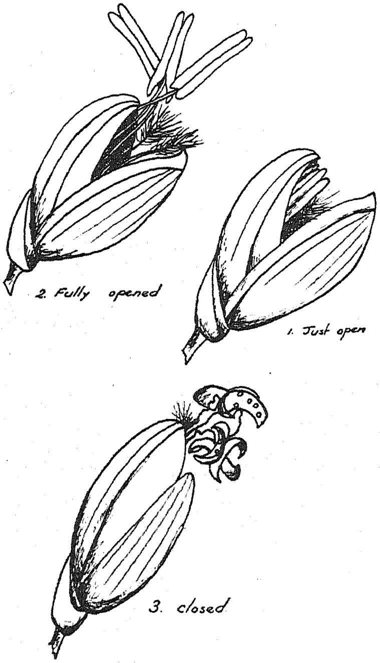

FIG. 1.—Three stages in the blooming of the millet spikelet.

A graphical representation of the hourly blooming record for a 24-hour period in percentage of total blooms for 1933 and 1934 is presented in Fig. 2. It should be noted that the varieties under observation were different for these two years. In 1933, only a single head from a farmer's variety was used; while in 1934, three heads from a selected strain (No. 48) were under observation. These were grown in pots that were placed in a small courtyard bounded on all sides by walls. In 1933, however, the observation was taken under field conditions and 2 weeks later than the observations made in 1934. Consequently, in 1933, the weather was growing much colder with a corresponding change in humidity. Furthermore, in 1934, we had the hottest summer on record for many years, and the observations were carried out in the midst of a hot spell, July 21 to August 2.

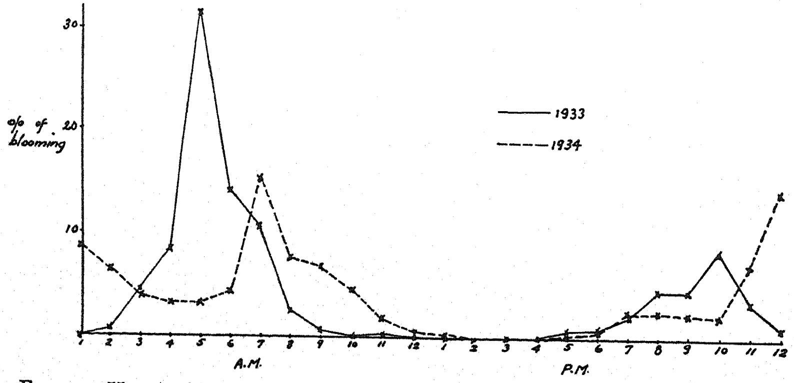

FIG. 2.—Hourly blooming record of millet, Kaifeng, China, 1933 and 1934.

In general, the two curves as shown in Fig. 2 are more or less similar to each other. There are two maxima for both curves. In 1933, the peak for the first period was almost three times as high as for the second and occurred between 4 and 7 a. m. The second period took place between 9 and 11 p. m. In 1934, both periods were almost equal in intensity, the first occurring between 6 and 8 a. m. and the second near midnight. Both periods in 1934 seem to have shifted to the right of those for 1933. This change can be explained by the difference in weather conditions under which the observations were made, as we shall see later that blooming is correlated negatively with temperature and positively with relative humidity. At any rate, our findings seem to agree closely with those obtained in India (2). There is practically no blooming between noon and 6 o'clock in the afternoon, when the temperature is relatively high and when the relative humidity is low.

INFLUENCE OF ENVIRONMENT

Since there are three variables involved in measuring the effect of environment on blooming, *viz.*, temperature, relative humidity, and light, a carefully controlled experiment would require the use of fine apparatus and technic to keep one variable under observation and the other two relatively constant. Unfortunately, our laboratory was not well enough equipped to do this. Nevertheless, we made hourly records of the number of blooms per hour. It was noted that there are always two maxima for the number of blooms in each day, one occurring about midnight and another about 7 o'clock in the morning. Both of these periods occur while the temperature is relatively low (around 75° F) and the relative humidity high. Conversely, when there is no blooming taking place, the temperature is high and the relative humidity low.

Calculating the correlation coefficient between the number of blooms and temperature, we find that $r = -0.1658$, $\eta = 0.1948$, and $\eta^2 - r^2 = 0.010457 \pm 0.00807$. It is apparent that r does not differ significantly from linearity. This correlation coefficient of -0.1658 for $n = 286$ is significant, since from Wallace and Snedecor (3), where $n = 300$ for a 5% level of significance $r = .113$ and for a 1% level of significance $r = .148$. On the other hand, the correlation coefficient between number of blooms and relative humidity is positive, r being 0.1774, $\eta = 0.2217$, and $\eta^2 - r^2 = 0.01768 \pm 0.01042$. Again r in this case does not differ from linearity. (The calculation used for r and η follows the method described by Hayes and Garber, 4). The correlation is again significant for the same level of significance as above. Thus, in general, we may conclude that the number of blooms is positively correlated with relative humidity and negatively correlated with temperature. However, this is inadequate to explain the observation for July 25, when there was practically no blooming at all, despite the fact that it rained the entire day with high relative humidity and relatively constant temperature (around 75° F). It seems that other factors must enter in, but lacking carefully controlled experiments, no further explanation can be made.

In order to observe the effect of light on blooming, one plant was placed in the same courtyard as described above, while another plant was moved into the house where it received only diffused light. Observations were started on July 26, 5 days after the other experiment had commenced. While no records were taken inside of the house, it is reasonable to expect that temperature, humidity, and light were all subject to change. The plant outside the house had two maximum periods of bloom, as can be seen by Fig. 3. The second period was almost 4 times as high as the first one, a difference that cannot be explained at this time. The two periods for the plant inside of the house, however, are about equal in intensity and occurred identically at the same time of day as in the plant outside of the house. Again, blooming occurred at almost every hour of the day, even in the afternoon when generally there is no blooming at all. For the lack of control of the other two variables, it is hard to give credit for this change to the effect of light alone.

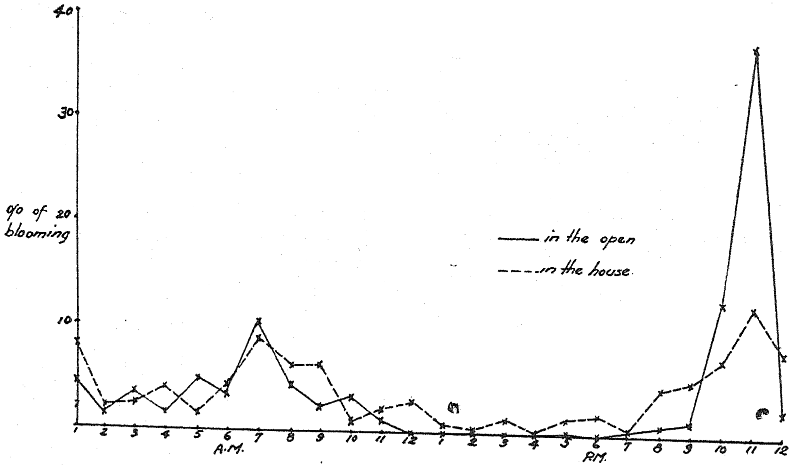

FIG. 3.—Hourly blooming record of millet indoors and in the open.

NATURAL CROSSING

In observation made on the anthesis of millet, it was found that the anthers usually dehisce after their full extrusion from the spikelet. Thus, it is obvious that there must be some natural crossing taking place in millet. Li (1) found the percentage of natural crossing to be 5.60 ± 2.10% in a total of 117,627 kernels at a distance of 1 foot, using non-waxy kernels found among waxy seeds as a criterion. Takahashi and Hoshino (5) found the percentage of natural crossing to be 0.59 as determined by the offspring with colored stems and leaf sheaths in the noncolored strains, but in different strains it varied from 0.09 to 1.09%. In a series of experiments with mixed sowings of colored and noncolored strains, these workers obtained up to 2.26% natural crossing. It seems, therefore, that our figure is a little too high, due possibly to faulty classification of the waxy and non-waxy kernels.

In order to check this point, 50 heads selected at random from the remnants of the previous experiment were planted each in a different row. At flowering time, pollen grains were gathered from each plant, stained with iodine solution, and examined under the microscope. In the case of waxy plants, the pollen grains stained yellow, while in hybrid plants obtained from natural crossing both yellow and red grains occurred in about equal numbers. This tedious work was discontinued when it was found that the hybrid plant could be picked out by macroscopic examination. The waxy strain used in this experiment was red seeded, with relatively short bristles. The non-waxy strain, on the other hand, had pale yellow seeds and much longer bristles. The hybrid invariably had long bristles. By separating the long-bristled heads from the short-bristled ones, we found that the former totaled 108 out of 1,416 plants. The percentage of natural crossing, therefore, was 7.63, a relatively close check on the previous work.

If this were true for conditions prevailing in Kaifeng, China, to what then could the differences observed by Takahashi and Hoshino (5) in Manchuria and Korea be attributed? This might be explained on two grounds. First, Kaifeng is a semi-desert region with relatively dry atmosphere as compared with that of Manchuria and Korea. Under this condition, the pollen grains can be blown from the place of liberation to the stigma of another plant much more easily. Second, the short-bristled waxy strain used in our experiment might favor the catching of foreign pollen by the exposed and unprotected stigma more readily than a strain with long bristles. Experiments using other strains of millet to determine this point are underway and the results will be reported in a later paper.

ARTIFICIAL HYBRIDIZATION

EMASCULATION

For the sake of carrying on genetical and breeding work with millet, a technic for artificial hybridization had to be developed. Owing to the minuteness of the spikelets of millet (about 1 mm in length), emasculation is very difficult. In fact, we tried repeatedly but failed each time. Fortunately, from the study of anthesis and from observations at other times, it was found that the anthers, as a general rule, shed their pollen outside of the glumes. This opened a way for artificial hybridization. In order to avoid stray pollen, hybridization should be done indoors or in the greenhouse. If it has to be done in the field, it is better to choose a quiet day.

After due protection with glassine bags for both parents, hybridization can be carried out when some of the spikelets from the parents are opening. With the help of a magnifying glass, examine the spikelet just opened. If the anthers are still intact after their full extrusion, pull them off immediately with a fine pair of forceps. Pollination can then be done either by applying pollen to the stigma from anthers of the male parent that are about to shed their pollen, or else by collecting the pollen grains by simply tapping the glassine bag that protects the male parent and applying this pollen to the stigma. Both methods seem to be equally successful. Pollination can be done immediately after emasculation or a day or two later. Preferably, emasculation and pollination of millet should be carried out early in the morning (around 6 o'clock).

BULK EMASCULATION

When many seeds are wanted from the same cross, especially for back crosses in genetical study, the method described above will not suffice. Hence, the bulk emasculation of flowers was tried out in 1933 and again in 1934. The method used was similar to that described by Stephens (6). A water container was made so that a thermometer could be inserted from the top and two millet heads to be treated could be inserted simultaneously from the ends. Treatments were carried out when there were some flowers opening on the head. During treatment, warm water at the right temperature was put into the container and the millet heads soaked in it. Invariably after the treatment, the temperature was 1° C lower than at the start of the experiment. After the treatment, the treated head was put together with the head to be used as the male parent and both heads covered with a glassine bag. Table 1 shows the results obtained.

TABLE 1.—*Results obtained in a mass emasculation experiment with millet.*

Temperature at start of experiment, ° C	Duration of soaking, min.	Estimated set of seed, %
46°	10	95
47°	15	60
47°	15	40
48°	10	40
48°	10	80
48°	20	10
48°	20	0
48.5°	10	20
48.5°	20	0
49°	10	40
49°	10	2
49°	10	5
49°	10	Few
49°	15	5
49°	20	Few
49.5°	15	50
50°	10	Few
50°	10	0
50°	20	0
51°	5	Few
52°	10	0

From Table 1 it will be seen that when the treatment temperature was beyond 50° C practically no seeds were set, even for short periods of treatment. Also, when the temperature was 48° or 49° C and applied for a longer duration, say at 20 minutes, this again was too severe.

The female parent used in this experiment had green-colored seedlings, and the male parent red seedlings, consequently the progeny should have had red seedlings. Tests of the progenies from the treated heads gave only a negligible number of red seedlings, but this was not sufficient to testify to the success of the treatment because when the pollen grains were killed at a given temperature and time, the ovules were likewise killed. Further experiment will be necessary to draw definite conclusion regarding this point.

CYTOLOGICAL STUDIES

Very little is known about the cytology of millet, hence in 1934, we made some preliminary studies. For the root tips, a chromic, acetic, and formalin solution was used in the following proportions:

Solution A		Solution B	
Chromic acid.......	3 grams	Formalin..............	90 cc
Glacial acetic acid...	21 cc	Distilled water.........	210 cc
Distilled water......	276 cc		

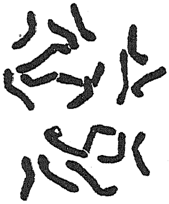

FIG. 4.—Metaphase plate of somatic mitosis of root tip of millet, showing 18 chromosomes. X 4,000.

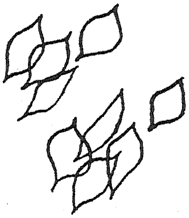

FIG. 5.—Metaphase plate of meiotic mitosis of millet, showing 9 pairs of chromosomes. X 4,000.

Equal parts of both solutions were mixed just before fixation. Paraffin sections were cut 10 microns thick. Newton's iodine gentian violet stain was used. For *Setaria italica*, selection No. 48, Hungarian millet, and one farmer's variety were examined. The common foxtail grass of Kaifeng, known locally as cow's grass, *S. viridis*, was examined also. All have 18 chromosomes as their somatic number (Fig. 4).

Among the nine pairs of chromosomes of *Setaria*, two seem to be longer in length, having submedium constrictions. The other seven shorter pairs are about equal in length and seem to have submedium constriction, except one which is constricted in the middle. However, the morphology of the chromosomes must be verified later.

For microsporogenesis, iron-aceto-carmine was used. Fig. 5 shows the first metaphase of *meiotic* mitosis having nine pairs of chromosomes. All other features of *meiosis* in the materials examined were normal. We may conclude from these results, therefore, that the chromosome number of *Setaria italica* and *S. viridis* is nine.

SUMMARY

1. There are two maximum periods of blooming in millet, one between 4 and 7 a. m. and another between 9 p. m. and midnight. In 1933, when the temperature was cooler, the first maximum was three times as high as the second. In 1934, when the temperature was higher, both periods were of about the same intensity. There was practically no blooming between noon and 6 p. m.

2. The rate of blooming was negatively correlated with temperature and positively correlated with humidity.

3. The percentage of natural crossing was found to be 5.60 ± 2.10 in 1933 and 7.63 in 1934, using the same material in both years but applying different criteria.

4. A method of artificial hybridization is described.

5. The somatic number of chromosomes of *Setaria italica* and *S. viridis* was found to be 18, and their haploid number 9.

LITERATURE CITED

1. LI, H. W. Studies in millet breeding methods. Bul. Col. Agr., Honan Univ., 2: 1–22. 1934. (In Chinese.)
2. RANGASWAMI AYYANGAR, G. N., NARAYANAN, T. R., and SESHADRI SARMA, P. Studies in *Setaria italica* (Beauv.), the Italian millet. Part I. Anthesis and pollination. Indian Jour. Agr. Sci., 3: 561–571. 1933.
3. WALLACE, H. A., and SNEDECOR, G. W. Correlation and Machine Calculation. Iowa State Col. Off. Pub., 30, No. 4: 1–71. 1931.
4. HAYES, H. K., and GARBER, R. J. Breeding Crop Plants. New York: McGraw-Hill Book Co. 1927.
5. TAKAHASHI, N., and HOSHINO, T. Natural crossing in *Setaria italica* (Beauv.) Proc. Crop Sci. Soc., Japan, 6: 3–19. 1934.
6. STEPHENS, J. C. Bulk emasculation of sorghum flowers. Jour. Amer. Soc. Agron., 25: 233–234. 1933.

THE BACKCROSS METHOD IN PLANT BREEDING[1]

FRED N. BRIGGS[2]

As early as 1922 Harlan and Pope[3] pointed out the usefulness of the backcross method in plant breeding, especially its utility in the transfer of specific characters from one variety to another. Later, the author[4] discussed its value in breeding disease-resistant varieties of cereals with special reference to work in developing varieties of wheat resistant to bunt, *Tilletia tritici*. There still seems to be some misunderstanding about the value of this method, due, it is believed, to a lack of appreciation of the fundamental principles involved. It seems appropriate, therefore, to describe how the backcross operates to bring about the desired results.

That homozygosity is increased at a rapid rate when plants are self-fertilized is well known to plant breeders. The proportion of homozygous individuals may be calculated from the following equation:

$$\text{Proportion of homozygosity} = \left(\frac{2^m - 1}{2^m}\right)^n$$

where m is the number of generations of selfing and n is the number of heterozygous genes. It is apparent that as m increases the proportion of homozygous individuals will become greater. With 10 pairs of factors over 85% of the population will be homozygous at the end of six generations. The number of homozygous genotypes equals 2^n where n is the number of pairs of factors. With the 10 pairs above the homozygous plants would be equally divided among 1,024 genotypes, therefore, either parent will occur once in 1,024 times among these homozygous individuals.

If a heterozygous population is continuously backcrossed to one of the homozygous parents, homozygosity is attained at the same rate as if self-fertilization is employed. Therefore, in the above equation m becomes the number of back-crosses used. For instance, with 10 pairs of factors, if the population is backcrossed six times, 85% of the population will be homozygous, but instead of there being 1,024 different homozygous genotypes, all the homozygous individuals will be of a single genotype, namely, that of the backcross or recurrent parent.

A simple cross between a white-kerneled club wheat and a red-kerneled lax wheat, in which the characters named depend on single factors, may be used to illustrate the difference between self-fertilization and backcrossing. The percentage of homozygosity and the percentage of the entire population which will be made up of parental combinations indicated may be seen in Table 1.

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[1] Contribution from the Division of Agronomy, University of California, Davis, Calif. Received for publication October 19, 1935.

[2] Assistant Professor.

[3] HARLAN, H. V., and POPE, M. N. The use and value of back-crosses in small grain breeding. Jour. Heredity, 13:319. 1922.

[4] Briggs, Fred N. Breeding wheats resistant to bunt by the back-cross method. Jour. Amer. Soc. Agron., 22:239–244. 1930.

TABLE 1.—*The percentage of homozygous individuals and parent combinations expected in five generations of self-fertilization as compared with five backcrosses to each parent in a cross of white-kernel club (parent I) x red-kernel lax (parent II) wheat cross.*

Generations	Self-fertilized		Backcrossed to P. I		Backcrossed to P. II	
	% homo	% homo white club or red lax	% homo	% homo white club	% homo	% homo red lax
1.............	25.00	6.25	25.00	25.00	25.00	25.00
2.............	56.25	14.06	56.25	56.25	56.25	56.25
3.............	76.56	19.14	76.56	76.56	76.56	76.56
4.............	87.79	21.97	87.89	87.89	87.89	87.89
5.............	93.84	23.46	93.84	93.84	93.84	93.84

You will note that the percentage of homozygous individuals is exactly the same in each of five backcrosses as it is in each of five generations of selfing. Where selfing is used, the homozygous individuals are equally divided among four genotypes, therefore, only one-fourth of these will have the same combination of the characters under consideration as either parent. On the other hand, where backcrossing is used, all the individuals will have the same combination as the recurrent parent.

It seems probable that the yield, quality, and adaptation of the best varieties of wheat, for example, in any locality may be due to the accumulation in these varieties of a fairly large number of favorable genes affecting these characters. Furthermore, it seems probable that many of these genes may exert a relatively small effect, so that they come under the category of modifying factors. Consequently, their presence in hybrid progenies is difficult to detect with the result that the selection of plants with such favorable combinations is extremely uncertain. If we assume only one heterozygous pair of genes for each chromosome pair in a wheat cross, there would be 2^{21}, or 2,097,152 different homozygous genotypes in subsequent generations, or the better parent type would occur only once in over 2,000,000 times. It will be apparent that the desirable characters of the more desirable parent may be preserved automatically by using it as the recurrent parent. Any factor or factors desired from the other parent will have to be maintained by selection.

The ease with which the backcross method can be used depends on a number of considerations. The simplest case is where the character to be transferred depends on a single gene about which the genetics is fully known. The frequency at which successive backcrosses may be made will depend on the ease with which the character to be transferred can be followed in hybrid populations. In transferring resistance to bunt from Martin to commercial varieties of wheat, the author has thought it desirable to get the resistant factor into the homozygous condition between each two or three backcrosses. In other cases it may be feasible to backcross every generation. At the end of the first backcross it may be possible to practice some selection to advantage, but after the third or fourth backcross the material is all so nearly like the recurrent parent that any selection of characters other than the one being transferred is not practical.

Even in many crosses where the main consideration is the increase of some more or less intangible character, such as quality or adaptation, a judicious amount of backcrossing might be employed to advantage. In any cross where one parent is more desirable commercially than the other, the F_1 may be backcrossed to the better parent without the likelihood of losing any genotypes, provided a reasonable number of backcrossed seed are made. However, there will be considerable shift in the progeny toward the recurrent parent. In the F_2 of a single cross either parent will appear once in 4^n plants, where n again is the number of pairs of heterozygous genes. However, at the end of the first backcross the recurrent parent will occur once in 2^n number of plants. Again assuming 21 pairs of factors the recurrent parent will occur once in 2,097,152 individuals where the F_1 is backcrossed, but the same parent will occur only once in 4,398,046,511,104 individuals in an F_2 from a single cross. Therefore, the recurrent parent combination would occur 2,097,152 times as often in the backcross as in the straight cross.

It seems to the author that the immediate need for such field crops as wheat is more dependable production. The plant breeder can accomplish much in this direction by adding disease and insect resistance to the best commercial varieties now available. The backcross method of breeding is admirably suited for such a program. Should one wish to add resistance to bunt and to stem rust to a commercial variety, for example, a separate backcross program should be set up for each disease and the end-products crossed together. If one has already produced a bunt-resistant strain, then it should be used as the recurrent parent because the resistance to bunt will then be taken care of automatically. Resistance to other diseases or additional factors for resistance to the same disease may be added from time to time as suitable parental material becomes available.

UNIFORMITY TRIALS WITH COTTON[1]

FU SIAO[2]

SINCE the publication of Mercer and Hall's paper in 1911, many studies have been made to determine desirable methods of conducting field trials. The primary purpose has been to learn the most efficient methods of making comparative tests. For certain groups of crops the general methods suggested by Love and Craig (7)[3] have been used extensively.

Only a few studies have been made with cotton. Engledow and Yule (2) suggested 1/80-acre plats with a few replications. Bailey and Trought (1), in 1928, recommended that the beds should be in long strips (up to 16 times as long as wide) and that where possible, each strip should be 1/5 feddan in area (1 feddan = 1.038 acres). They recommended 10 replications, and where sufficient land or seed was not available, the number of replications might be made up by dividing the strip into sections. Because of great seasonal variations, they stated that the trial should be carried out over a period of at least 3 years. Ligon (5) suggested the use of single row plats not longer than 100 feet, with three replications.

The results of these investigators differ widely and no generalization can be made. A blank test was carried out by the writer over a period of 3 years, beginning in 1930, at Yuyao, Chekiang, China, in the hope of throwing some light on desirable methods of field experimentation with cotton. This paper summarizes the results of that test.

MATERIALS AND METHODS

Two hundred rows of cotton each 24 feet long, and spaced 1 foot apart were planted in a single series in 1930 and in 1931. Seed was sown in drills and the seedlings were thinned finally to 30 plants per row, more or less evenly distributed. In 1932, 22 ridged beds each 192 feet long were planted with the same variety of cotton. The beds were 4.5 feet in width and occupied by three rows of cotton. Each bed was cut into 12 sections and the crop from each section harvested separately. Owing to the existence of border effect the plats on the border were discarded. As a result only 200 plats arranged in a 20x10 block were used in the analysis.

Varying numbers of single rows were combined to form plats of different width for the study of the most efficient size of plat. In each case 25 varieties were assumed in the test except for the three-row plats in 1932 where only 20 varieties were assumed. In 1932 the size of plat was increased in both directions by extending the length of the plat or by expanding the width of the plat. Because of the

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[1] Contribution from the Division of Agronomy and Plant Genetics, University of Minnesota, St. Paul, Minn. This paper is a summary of a thesis submitted to the Graduate School of the University of Minnesota as a partial fulfillment of the requirements for the degree of master of science, June 1934. Received for publication October 31, 1935.

[2] Graduate Student. The writer wishes to express his appreciation to Dr. H. K. Hayes, Chief of the Division of Agronomy and Plant Genetics, for his helpful direction throughout the analysis of the data and in the preparation of the manuscript.

[3] Reference by number is to "Literature Cited", p. 979.

difference in basic size of plat and in arrangement of the plats, the results for 1932 were treated separately from 1930 and 1931. The method of "Analysis of Variance" suggested by Fisher (3) was used in the analysis of the results. The efficiency of different sizes of plats was obtained by dividing the calculated variance of a plat of basic size by the product of the variance of larger plats and the number of basic plats making up the larger plat. Harris' (4) method of estimating soil heterogeneity was applied in 1932 to trace the direction of the soil variation.

Randomized blocks, Latin squares, and systematic arrangement of plats were compared by finding the distribution of the differences between the assumed varieties.

The standard error for systematic arrangement was based on the check plats only which were assumed to occur every fifth plat. The theoretical yield of the test plats was obtained by the grading method suggested by Love (6). Then the difference between the yield of the assumed varieties and the theoretical yield was calculated and compared with the standard error of a mean difference. A standard error calculated from an analysis of variance was used to obtain a standard error of a mean difference between the assumed varieties in randomized blocks and in Latin squares. The distribution of differences from these three methods of arrangement was tested by the X^2 test against the theoretical random distribution.

EXPERIMENTAL RESULTS

SIZE OF PLAT

The data in Table 1 show a gradual reduction of experimental error as the plat increased in size. The coefficient of variability in 1930 dropped from 14.05% to 9.86% as the plat increased from a single row to eight rows in width. In 1931 the change in the coefficient of variability for the same increase in size of plat was from 22.34% to 12.75%, or a reduction of about 44% of the total. The difference in the amount of reduction of error between these two years might be attributed to the wide differences in yield. It is generally true that the experimental error is larger in an unfavorable season and larger plats are more advantageous under these conditions.

TABLE 1.—*Standard errors and coefficients of variability for different sizes of plats in 1930 and 1931.*

Size of plat	1930		1931	
	S. E.	C. V.	S. E.	C. V.
One-row	18.54	14.05	13.80	22.34
Two-row	19.21	14.54	11.65	18.85
Three-row	16.51	12.69	11.10	17.90
Four-row	16.57	12.53	9.99	16.17
Eight-row	13.03	9.86	7.88	12.75

Increasing the size of plat decreases the variability of the experiment by increasing the precision of a single plat yield. On the other hand, there is an increase in the variability within the block through expanding the area included in the block. There are two opposing tendencies that affect the experimental error as the plat changes in size, the final result being due to a balance between these two tendencies. The slow rate of reduction in experimental error through increase in size of plat and, in some exceptional cases, the greater variability for larger plats, may be explained by increase in variation within the block as the plat increases in size.

The efficiency of different sizes of plats was calculated on the single-row plat basis in order to compare the relative efficiency of plats of varying size for a given area of land. The results are summarized in Table 2. Taking the single-row plat as a basis in 1930, the two-row plat was only 46.58% as efficient; that is to say, a test in two-row plats was only 46.58% as accurate as a test in single-row plats replicated once. The two-row plats in 1931 were only 70.16% as efficient as the single-row plat replicated once. For these two years there was a gradual reduction in efficiency as the plat increased in size. In other words, the larger the plat the lower the efficiency. The lower efficiency was entirely due to the existence of soil heterogeneity. Had the soil variation been uniform over the entire field, the different sizes of plat would be equal in efficiency.

TABLE 2.—*The relative efficiency of different size of plat in 1930 and 1931.*

Size of plat	1930		1931	
	Variance	Efficiency	Variance	Efficiency
One-row	343.92	100.00	190.39	100.00
Two-row	369.16	46.58	135.68	70.16
Three-row	272.46	42.08	123.14	51.54
Four-row	274.47	31.32	99.81	47.69
Eight-row	169.69	25.33	62.06	38.35

Since the plats were arranged in a 20 x 10 block in 1932, there was an opportunity to increase plat size in both directions. In the following discussion increasing the length of plat will be referred to as "by length" and expanding the width of the plat as "by width." The former extension would include plats on the same bed, while the latter combines the plats on adjacent beds. Results are given in Table 3.

A two-unit plat had a much smaller error than a single-unit plat no matter in which way the plat was expanded. The coefficient of variability was reduced from 10.13% for a one-unit plat to 7.14% for a two-unit plat by width and to 8.06% for a two-unit plat by length. The efficiency of the two-unit plat by width was 100.86 and that of two-unit plat by length was 79.19. The high efficiency for the two-unit plat by width was not expected. A correlation coefficient of .061 ± .058 revealed no association between adjacent plats; consequently, the two-unit plat by width should be equal in effi-

TABLE 3.—*Variance and efficiency of different size of plats in 1932.*

Size of plat	Variance	C. V.	Efficiency
One-unit	464.92	10.13	100.00
Two-unit (by width)	230.47	7.14	100.86
Two-unit (by length)	293.81	8.06	79.12

ciency to a one-unit plat. The loose association between adjacent plats was due probably to the fact that these plats were on two ridged beds separated by a furrow.

The results indicated the wide plat was more desirable than a long narrow plat. To be more exact, the most suitable shape of the plat was determined by the degree of association of adjacent plats. The plat extended in the direction of least association or greatest variation is the most desirable.

REPLICATION

The number of replications needed to attain a certain degree of accuracy may be found by dividing the standard error of a unit plat by the desired error and squaring the quotient. The theoretical number of replications to reduce the standard error to 5% for different sizes of plats is given in Table 4. For single-row plats only 7.9 replications were needed in 1930, while 20 replications were required to attain the same degree of accuracy in 1931. For an eight-row plat 3.9 replications were needed in 1930 and 6.5 replications in 1931. This fact shows that in an unfavorable season the larger plat was more advantageous than under more favorable conditions. Because of wide difference in variability, no definite number of replications can be recommended.

TABLE 4.—*Theoretical number of replications needed to reduce the standard error to 5%.*

Size of plat	1930	1931
One-row	7.9	20.0
Two-row	8.5	14.2
Three-row	6.4	12.8
Four-row	6.3	10.5
Eight-row	3.9	6.5

Twenty varieties were assumed to be tested in 200 rows in 1930 and 1931 and in 200 plats in 1932. This gave opportunity to study either five or ten replications for randomized blocks and four or eight replications for systematic arrangement for the year 1930 and 1931, and to study the arrangement in randomized blocks and Latin squares in 1932. Theoretically, the mean differences between the assumed varieties should be zero, and therefore, the differences should be distributed normally around this mean. Because of the similar nature of the data from 1930 and 1931, the distribution of the differences between the assumed varieties were entered in the same frequency table and tested by the X^2 test for goodness of fit. Table 5 shows the distribution of differences where five replications were used in randomized blocks. A X^2 value of 3.04 was obtained, which, according to Elderton's table (8) for $n' = 6$, gave a P value of .69.

For ten replications in randomized blocks, the calculated X^2 value was 8.21 with a P value of .09. The result indicated that the departure of the observed distribution from the theoretical was non-significant.

TABLE 5.—*X^2 test for goodness of fit between the observed and expected distribution of differences in randomized blocks between the hypothetical varieties with five replications for 1930 and 1931 combined.*

Class limit in S. E.	Observed	Calculated	(O–C)	$(O-C)^2/C$
±. 00–± .49	288	291	3	.03
± .50–± .99	224	228	4	.07
±1.00–±1.49	143	140	3	.06
±1.50–±1.99	65	67	2	.06
±2.00–±2.49	26	25	1	.04
±2.50–±2.99	14	9	5	2.78
				$X^2 = 3.04$

In systematic arrangement one-fifth of the total area was occupied by the assumed check variety. Consequently, only four or eight replications were possible where five or ten replication could be accommodated for randomized blocks. The differences between the observed yield of the plat and the theoretical yield were calculated by the grading method from the adjacent check plats, and then were entered in the distribution table in the intervals of standard error of the mean difference. A X^2 test was applied to test the goodness of fit between the observed and calculated distribution. With four replications X^2 equaled 4.33, with $n' = 4$, giving a P value of .23 or a chance of 23 out of 100 in favor of the occurrence of such a deviation due to chance alone. The X^2 value for eight replications was below 1 and gives a P value above .80.

The same method was followed in studying replication in 1932. The distribution of the differences between hypothetical varieties is given in Table 6. The last class included all the frequencies above 2.0 x S. E. as the individuals above that class were too few to be treated as a single class. In the Latin squares the class 1.50 to 1.99 included all differences above 1.50. In randomized blocks the calculated X^2 value of 5.87 with an $n' = 4$ gave a P value of .21. In Latin squares X^2 being 4.34 with $n' = 4$ led to a P value of .23. The distribution of the differences between the hypothetical varieties were according to expectation.

TABLE 6.—*Frequency distribution of difference between hypothetical varieties arranged in Latin squares and randomized blocks, 1932 data.*

Ranges in S. E.	Randomized blocks			Latin squares		
	Expected	Observed	Diff.	Expected	Observed	Diff.
± .00–± .49	73	63	10	36	35	1
± .50–± .99	57	58	1	28	21	7
±1.00–±1.49	35	47	12	17	23	6
±1.50–±1.99	17	15	2	9	11	2
±2.00 and above	8	7	1	—	—	–

The randomized blocks because of the local control had an experimental error lower than with systematic arrangement and in turn Latin squares gave a lower error than randomized blocks through the control of error in both directions. In 1930, for ten replications in randomized blocks, the standard error was 5.91 and for eight replications in systematic arrangement the standard error was 8.20. In 1931 the standard errors were 4.39 and 5.15 for randomized blocks and systematic arrangement, respectively. In 1932 in comparing the randomized blocks and Latin squares the variances were 46.49 and 34.42, respectively.

SUMMARY

1. Increase in size of plat was accompanied by reduction in experimental error, but larger plats were lower in efficiency than the smaller plats. This indicated that increase in number of replications was much more efficient than increasing the size of plat.
2. The shape of the plat was determined by the direction of soil variation. The increase in size of plat in the direction of least association was most efficient.
3. Because of high seasonal variation no definite number of replications could be recommended. Each of the three methods of replication, *viz.*, systematic arrangement, randomized blocks, and Latin squares, were studied and differences between hypothetical varieties compared with calculated standard errors. By means of X^2 for goodness of fit each gave good agreement with mathematical expectation.

LITERATURE CITED

1. BAILEY, M. A., and TROUGHT, T. An account of experiments carried out to determine the experimental error of field trials with cotton in Egypt. Egypt Min. Agr. Tech. and Sci. Serv. Bul. 63. 1926.
2. ENGLEDOW, F. L., and YULE, G. U. The Principles and Practice of Yield Trials. London: Empire Cotton Growing Corp. Rev. ed. 1928.
3. FISHER, R. A. Statistical Methods for Research Workers. Edinburgh: Oliver & Boyd. Ed. 4. 1932.
4. HARRIS, J. A. On the calculation of intraclass and interclass coefficient of correlation from class moments when the number of possible combinations is large. Biometrika, 9: 446–472. 1913.
5. LIGON, L. L. Size of plat and number of replication in field experiments with cotton. Jour. Amer. Soc. Agron., 22: 689–699. 1930.
6. LOVE, H. H. Directions for rice improvement in China. Chekiang Agr., I: 43–72. 1933.
7. ———— and CRAIG, W. T. Methods now in use in cereal breeding and testing at the Cornell Agricultural Experiment Station. Jour. Amer. Soc. Agron., 16: 109–127. 1924.
8. PEARSON, K. Tables for Statisticians and Biometricians. Part I. Biometric Laboratory, University College, London. Ed. 2. 1923.

STATISTICAL ANALYSES APPLIED TO RESEARCH IN WEED ERADICATION

Frank F. Lynes[1]

THE following article is a preliminary report of investigations being conducted in Otero County, Colo. It is believed to be the first report of the use of variance analysis in weed eradication research. The value of the data given is limited in as much as it involves only a 1-year test, but the method employed is believed to be a progressive step in scientific weed research.

For this particular test the randomized-block method was selected because of its adaptability to tests which are planned for the future. This method, developed by Fisher (3),[2] is particularly adapted to research work conducted in connection with the Otero County weed eradication program.

For this test a *Convolvulus arvensis* (wild morning glory or field bindweed) area was selected on the George Seamans' farm, located 3 miles east and 1½ miles south of Rocky Ford, Colo. The experiment consisted of 15 treatments and 5 replications with plats 1 square rod in size. The plat arrangement and treatment were as follows:

Plat arrangement and treatment number.

Block I	Plat	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75
	Treatment	15	2	13	10	3	9	11	8	4	12	6	7	5	1	14
Block II	Plat	4	9	14	19	24	29	34	39	44	49	54	59	64	69	74
	Treatment	14	7	9	2	13	10	5	11	8	15	4	6	12	3	1
Block III	Plat	3	8	13	18	23	28	33	38	43	48	53	58	63	68	73
	Treatment	5	4	13	8	11	7	1	14	10	9	12	3	2	15	6
Block IV	Plat	2	7	12	17	22	27	32	37	42	47	52	57	62	67	72
	Treatment	3	15	12	1	6	9	8	7	5	14	10	2	4	13	11
Block V	Plat	1	6	11	16	21	26	31	36	41	46	51	56	61	66	71
	Treatment	15	11	8	14	13	2	1	5	10	9	6	4	12	7	3

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[1] In charge, Otero County, Colorado, Weed Eradication Program, Rocky Ford, Colo.

The writer wishes to express his appreciation to G. W. Deming, Assistant Agronomist, U. S. Dept. Agriculture, for his helpful criticism in the preparation of this article. Received for publication October 3, 1935.

[2] Figures in parenthesis refer to "Literature Cited", p. 987.

Treatments.

Treatment No.	Treatment	Plat No.
1	1 bbl. beet molasses	17, 31, 33, 70, 74
2	¾ bbl. beet molasses	10, 19, 26, 57, 63
3	½ bbl. beet molasses	2, 25, 58, 69, 71
4	¼ bbl. beet molasses	8, 45, 54, 56, 62
5	3 lbs. Atlacide dissolved in 1 gal. water	3, 34, 36, 42, 65
6	3 lbs. sodium chlorate dissolved in 1 gal. water	22, 51, 55, 59, 73
7	3⅛ gal. Crafts acid arsenical	9, 28, 37, 60, 66
8	Same as No. 7 plus 3⅛ gal. water next a.m.	11, 18, 32, 40, 44
9	Same as No. 8 plus straw before applying water	14, 27, 30, 46, 48
10	2% solution of acid arsenical stock solution	20, 29, 41, 43, 52
11	Acid injury plus treatment No. 7	6, 23, 35, 39, 72
12	Acid injury plus treatment No. 8	12, 50, 53, 61, 64
13	Check (no treatment)	13, 15, 21, 24, 67
14	Cleaned off all vegetation then applied No. 5	4, 16, 38, 47, 75
15	Cleaned off all vegetation then applied No. 6	1, 5, 7, 49, 68

The toxic effect of Steffins House discard beet molasses on succulent weeds has been brought to the attention of the writer and instances of its use in the eradication of bindweed have been reported. Beet molasses was included in this test to gain more definite information as to its possible value as a weed eradicator. The molasses was furnished by the Rocky Ford factory of the American Crystal Sugar Company. Their analysis of the molasses is as follows:

Approximate analysis:

Sucrose	55%
Rafinose	2½%
Water	20%
Organic matter	22½%

Dry substance	80.17%
Total nitrogen	1.68%
Nitrate nitrogen	0.52%
Carbonate ash	13.05%

Analysis of ash:

SiO_2	0.04%
Fe_2O_3 and Al_2O_3	0.03%
CaO	0.11%
MgO	0.03%
K_2O	5.57%
Na_2O	2.15%
SO_3	1.55%
Cl	1.66%
CO_2	2.35%
	13.49%
O–CL equiv	0.38%
	13.11%

Combined:

KCL	3.50%
K_2SO_4	3.39%
K_2CO_3	2.23%
$CaCO_3$	0.19%
$MgCO_3$	0.07%
Na_2CO_3	3.67%
SiO_2	0.04%
Fe_2O_3 and Al_2O_3	0.03%
	13.12%

The molasses was applied by buckets with perforated bottoms in order to obtain a uniform coverage of each plat with the desired amount of molasses. For some time there has been a controversy between weed workers as to the comparative value of chlorate treatments. Four of these treatments were incorporated in this test in order to obtain data as a basis for recommendations for the use of chlorates in the weed program.

Crafts acid arsenical spray was incorporated in the test because at present it is the leading spray employed in the Otero County weed eradication program. It has been suggested that an application of water the following morning will considerably increase the effectiveness of this spray and this was incorporated in the test to obtain an indication of its value. It has also been suggested that covering the area with straw and then applying the water would maintain a high humidity and thus considerably increase the effectiveness of the spray. This was also incorporated to obtain an indication of its value. The use of jars or cans placed some distance apart and filled with a 2% solution of the acid arsenical stock solution into which the tops of the adjacent plants are immersed has also been suggested and was used in this test.

Crafts (1, 4) has suggested that any agent which kills the leaves but not the stems will cause the production of a secondary tissue which is more efficient for the rapid conduction of water than the normal stem. A concentration experiment for leaf injury to produce secondary growth was carried on at the Rocky Ford substation of the Colorado Agricultural Experiment Station. All plats were ⅓ square rod in size.

Various dilutions of commercial sulfuric acid (66° Baume) were applied on August 7, 1934 at the rate of 1 gallon per plat. The results are given in Table 1.

TABLE 1.—*Effect of sulfuric acid on field bindweed.*

Plat No.	Amount of acid per gal.	Normality	Percentage (vol.)	Observations, Aug. 20, 1934
1	1 qt.	0.5	25.00	Burnt off all vegetation
2	1 pt.	0.25	12.50	Burnt off all vegetation
3	½ pt.	0.125	6.25	Burnt off all vegetation
4	¼ pt.	0.0625	3.125	Killed all vegetation
5	⅛ pt.	0.03125	1.56	Few live stems
6	4 tbs.	0.025	1.25	Few live stems
7	3 tbs.	0.01875	0.94	Many live stems
8	2 tbs.	0.0125	0.62	All stems alive and parts of leaves alive
9	1 tbs.	0.00625	0.31	No appreciable injury

From the data it may be assumed that 1 gallon of a 0.5% solution by volume of commercial sulfuric acid per ⅓ square rod, or 3 gallons per square rod, would produce the desired injury.

The following method was used in preparing, and applying the acid arsenical treatments (2). A stock solution is prepared as follows:

	As_2O_3	NaOH	H_2O (cold)
By weight	4 parts	1 part	3 parts
Mixture	44.464 lbs.	11.116 lbs.	4 gal.

This makes 5½ gallons of stock solution containing 50% As_2O_3 by weight. The As_2O_3 and NaOH are mixed thoroughly in the dry state in an iron container and the cold water added slowly. The mixture should be worked in the open to avoid the fumes.

The spray solution is then prepared by adding 1 gallon of the stock solution and 5 gallons of commercial sulfuric acid (66° Baume) to 200 gallons of water.

Prof. Bruce J. Thornton, Associate Botanist, Colorado State College, gives the following directions for applying the spray: The plants must be mature; the soil not excessively moist; applications made between 6:00 and 12:00 p.m.; employ No. 4 size nozzle at 125 lbs. pressure, applying 500 to 600 gallons per acre; plants should be thoroughly wet and an excess of spray should be built up on the foliage if possible; a thorough application of water the next morning considerably increases the effectiveness.

The chlorate treatments were also applied according to the recommendation of Professor Thornton, as follows: Three pounds of the material dissolved in 1 gallon of water and applied at 125 lbs. pressure using No. 1 size nozzle. This test was conducted in the spare time of the writer and for that reason the application of the various treatments extended over a longer period of time than is desirable.

A schedule of the dates of application of the treatments is given below.

1934 data

Date of Treatment	Remarks
Aug. 15 to 25	Stand counts
Aug. 15 and 16	Applied beet molasses
Aug. 25	Placed cans 3 feet apart for 2% stock solution for treatment No. 10
Aug. 27	Applied Atlacide, treatment No. 5
	Applied 2% solution of acid arsenical stock solution at 6:00–7:00 p.m.
	Cleaned off all vegetation for Atlacide treatment No. 14
Aug. 28	Applied Crafts acid arsenical at 10:30 p.m. to 3:00 a.m.
Aug. 29	Cleaned off all vegetation for sodium chlorate treatment No. 15
	Applied straw and water for treatment No. 9
	Applied water for treatment No. 8
Sept. 12	Applied acid injury treatment for treatment Nos. 11 and 12 in the afternoon
Sept. 15	Applied sodium chlorate for treatment Nos. 6 and 15 in the afternoon
Sept. 20	Applied acid arsenical treatment for treatment Nos. 11 and 12 at 10:00–11:00 a.m.

1935 data

July 13	Stand counts

Soil samples were taken on the area on September 5, 1934, to ascertain the moisture content and the results presented in Table 2.

TABLE 2.—*Soil sample data.*

Plat No.	Depth, inches	Weights, grams					Moisture %
		Wet	Oven dry	Oven dry jar	Oven dry soil	Total moisture	
3	0–18	448.8	438.5	303.4	135.1	10.3	7.62
	18–60	624.5	596.0	284.0	312.0	28.5	9.13
28	0–18	511.2	490.2	297.6	192.6	21.0	10.90
	18–60	592.0	567.2	298.4	268.8	24.8	9.23
73	0–18	423.9	408.7	301.4	107.3	15.2	14.17
	18–60	443.7	420.3	283.5	136.8	23.4	17.11

Weather data covering the winter season preceeding the test and the period during which the test was conducted are presented in Table 3.

TABLE 3.—*Weather data.**

Date	Temperature		Mean temperature		Total precipitation, in.
	Max.	Min.	Max.	Min.	
Oct. 1933...	80°	26°	72°	35°	0
Nov. 1933..	70°	12°	57°	24°	0.13
Dec. 1933...	69°	12°	51°	24°	0.87
Jan. 1934...	64°	9°	50°	19°	0.05
Feb. 1934...	70°	7°	47°	23°	1.03
Mar. 1934..	75°	4°	57°	26°	0.27
Apr. 1934...	83°	24°	67°	38°	0.84
May 1934...	94°	34°	81°	51°	0.74
June 1934...	100°	46°	91°	54°	0.37
July 1934...	106°	55°	99°	62°	1.19
Aug. 1934...	102°	41°	94°	60°	1.80
Sept. 1934..	92°	29°	81°	46°	0.88
Oct. 1934...	94°	25°	77°	38°	0
Nov. 1934..	80°	8°	61°	25°	0.15
Dec. 1934...	64°	3°	50°	17°	0.05
Jan. 1935...	68°	—12°	54°	17°	0
Feb. 1935...	75°	0°	53°	19°	0
Mar. 1935..	81°	18°	63°	30°	0.37
Apr. 1935...	82°	20°	66°	36°	0.48
May 1935...	88°	26°	68°	44°	2.45
June 1935...	98°	42°	87°	53°	1.01
July 1935...	101°	54°	96°	59°	0

*Data furnished by Herman Fauber in charge of the Rocky Ford Sub-station.

In order to have an accurate criterion to rely upon for a comparison of these widely different treatments, actual stand counts were made on the plats and are presented in Table 4, together with the calculated percentages of return growth. A square meter quadrat, as used in range work, was employed in obtaining the counts. The quadrat was placed at random approximately in the center of each plat and the number of shoots at the ground line determined. The reason for placing the quadrat near the center of the plat was to avoid possible border effects from adjacent treatments. A statistical analysis of the data is presented in Table 5.

According to this analysis, treatments Nos. 5, 6, 7, 9, 14, and 15 are significantly better than the check and there are no significant differences between these treatments. Further, this analysis indicates that:

1. The chemicals now in use give a significant kill.
2. The chlorates may be applied as a soil treatment or as a foliage spray without any significant differences in the kill.
3. There is no significant difference between Altacide and sodium chlorate.
4. Crafts acid arsenical is as effective as the chlorates.
5. The modifications of Crafts spray are not significantly different from his spray.

TABLE 4.—*Stand counts of field bindweed.*

Plat No.	1934 stand	1935 stand	% return	Plat No.	1934 stand	1935 stand	% return	Plat No.	1934 stand	1935 stand	% return
1	101	8	7.92	27	374	165	44.12	53	374	118	31.55
2	309	105	33.98	28	403	136	33.75	54	525	335	63.81
3	180	100	55.56	29	382	264	69.11	55	516	75	14.53
4	400	58	14.50	30	484	203	41.94	56	399	72	18.05
5	407	64	15.72	31	397	116	29.22	57	436	160	36.70
6	168	118	70.24	32	452	112	24.78	58	429	249	58.04
7	293	27	9.22	33	613	90	14.68	59	456	65	14.25
8	412	190	46.12	34	413	122	29.54	60	316	212	67.09
9	330	115	34.85	35	393	431	109.67	61	331	98	29.61
10	431	150	34.80	36	593	130	21.92	62	504	303	60.12
11	190	75	39.47	37	484	80	16.53	63	388	248	63.92
12	342	189	55.26	38	416	120	28.85	64	372	141	37.90
13	518	195	37.64	39	602	282	46.84	65	419	67	15.99
14	389	109	28.02	40	607	270	44.48	66	462	69	14.94
15	415	246	59.28	41	388	130	33.51	67	362	290	80.11
16	165	85	51.52	42	674	148	21.96	68	444	20	45.05
17	495	133	26.87	43	555	304	54.77	69	489	545	111.45
18	283	139	49.12	44	472	122	25.85	70	447	345	77.18
19	490	80	16.33	45	564	456	80.85	71	401	505	125.94
20	365	310	84.93	46	325	63	19.38	72	139	146	105.04
21	274	181	66.06	47	511	110	21.53	73	225	128	56.89
22	510	117	22.94	48	513	58	11.31	74	364	166	45.60
23	473	212	44.82	49	545	98	17.98	75	316	132	41.77
24	375	235	62.67	50	543	344	63.35	76	120	0	0
25	456	216	47.37	51	341	40	11.73	—	—	—	—
26	222	114	51.35	52	490	236	48.16	—	—	—	—

TABLE 5.—*Analysis of data arranged according to treatments.*

No.	Treatment	Block I	Block II	Block III	Block IV	Block V	Total	Average
1	1 bbl. beet molasses	77.18	45.60	14.68	26.87	29.22	193.55	38.71
2	¾ bbl. beet molasses	34.80	16.33	63.92	36.70	51.35	203.10	40.62
3	½ bbl. beet molasses	47.37	111.45	58.04	33.98	125.94	376.78	75.36
4	¼ bbl. beet molasses	80.85	63.81	46.12	60.12	18.05	268.95	53.79
5	3 lbs. Atlacide dissolved in 1 gal. water	15.99	29.54	55.56	21.96	21.92	144.97	28.99
6	3 lbs. sodium chlorate dissolved in 1 gal. water	14.53	14.25	56.89	22.94	11.73	120.34	24.07
7	3⅛ gal. Crafts acid arsenical spray	67.09	34.85	33.75	16.53	14.94	167.16	33.43
8	Same as 7 plus 3⅛ gal. water next a.m.	44.48	25.85	49.12	24.78	39.47	183.70	36.74
9	Same as 8 plus straw before applying water	41.94	28.02	11.31	44.12	19.38	144.77	28.95
10	2% solution acid arsenical stock solution	84.93	69.11	54.77	48.16	33.51	290.48	58.10
11	Acid injury plus 7	109.67	46.84	44.82	105.04	70.24	376.61	75.32
12	Acid injury plus 8	63.35	37.90	31.55	55.26	29.61	217.67	43.53
13	Check (no treatment)	59.28	62.67	37.64	80.11	66.06	305.76	61.15
14	Cleaned off all vegetation then applied 5	41.77	14.50	28.85	21.53	51.52	158.17	31.63
15	Cleaned off all vegetation then applied 6	15.72	17.98	45.05	9.22	7.92	95.89	19.18
	Totals	798.95	618.70	632.07	607.32	590.86	3247.90	

Σd^2 plats 189465.5230—140651.3921 = 48814.1309

Σd^2 blocks 2138576.3994 ÷ 15 = 142571.7599—140651.3921 = 1920.3678

Σd^2 treatments 812448.7784 ÷ 5 = 162489.7557—140651.3921 = 21838.3636

Subtraction factor $\frac{(3247.90)^2}{75} = 140651.3921$

Analysis of variance:

	Sum of Squares	D.F.	Mean Square	½ Log e	
Blocks	1920.3678	4			
Treatments	21838.3636	14	1559.88311	3.67619	5% point <.3691
Error	25055.3995	56	447.41785	3.05175	1% point <.5224
Total	48814.1309	74			Z value .6244

Level of significance:

S. E. of plat $\sqrt{447.41785} = 21.1522540$

S. E. of a mean $21.1522540 \div \sqrt{5} = 9.4595755$

S. E. of a difference $9.4595755 \times \sqrt{2} = 13.3778603$

Difference required for significance 2 x 13.3778603 = 26.7557206 or 26.76

6. Beet molasses is not effective in the concentrations used in this experiment.

In spite of the ineffectiveness of beet molasses in this experiment it is effective in greater concentrations as indicated by the results obtained on plat 76. This plat was located on an adjacent area and was 1 square meter in size. One-half barrel of beet molasses was applied to this plat. Although this concentration was effective, at the present cost of $2.00 a barrel this treatment would not be practical.

SUMMARY

The value of the data presented here is limited inasmuch as they cover only a 1-year test. However, the methods employed should offer a means of accurately comparing methods of weed eradication. It is the earnest hope of the writer that this report will inspire other workers to utilize variance analysis in their experimental work on weed eradication. The use of stand counts offers an accurate means of comparing the percentage kill.

The analysis indicates that the chemicals now in use give a significant kill and that there is no significant difference between the chlorates and the acid arsenical. Since the arsenical spray is cheaper and does not have a residual effect on the soil, making it possible to grow a crop on the land each year to help defray the cost of application, it would seem to be more economical for use in Otero County, Colo., in the eradication of *Convolvulus arvensis* (field bindweed) than are the chlorates.

LITERATURE CITED

1. CRAFTS, A. S. Sulfuric acid as a penetrating agent in arsenical sprays for weed control. Hilgardia, 8: 25–147. 1933.
2. ————. The use of arsenical compounds in the control of deep-rooted perennial weeds. Hilgardia, 7: 361–372. 1933.
3. FISHER, R. A. Statistical Methods for Research Workers. Edinburgh: Oliver and Boyd. Ed. 4. 1932. (Pages 190–262.)
4. KENNEDY, P. B., and CRAFTS, A. S. The anatomy of *Convolvulus arvensis*, wild morning-glory or field bindweed. Hilgardia, 5: 591–622. 1931.

THE ASSIMILATION OF PHOSPHORUS BY *ASPERGILLUS NIGER* AND *CUNNINGHAMELLA* SP.[1]

F. B. SMITH, P. E. BROWN, AND H. C. MILLAR[2]

NUMEROUS biological methods for determining the available phosphorus in soils have been proposed. These methods are all based upon the assumptions that the growth of certain soil microorganisms is proportional to the amount of available phosphorus present in the soil and that all the phosphorus available to the micro-organisms would be available to crop plants.

In an investigation of the effect of phosphorus on nitrogen fixation by Azotobacter, Thompson and Smith (4)[3] obtained results which indicated that large amounts of phosphorus were not assimilated by the Azotobacter and hence were not necessary for their growth.

Koszelecki (1) grew *Aspergillus niger* in a medium containing 10% glucose, 1% asparagin, 0.5% $MgSO_4$, 0.1% KCl, 0.001% $ZnSO_4$, and phosphorus supplied in 100, 50, or 25 grams of soil. The mycelium was weighed after 6 days and analyzed for phosphorus. The amount of phosphorus assimilated was found to be 1:200 of the weight of the mycelium.

Simakova and Bovschik (3) determined the amount of phosphorus assimilated by *Aspergillus niger* after 6 days. They found that the amount of phosphorus in the mycelium was directly proportional to the amount of phosphorus in the medium.

Thompson, Smith, and Brown (5) found that *Aspergillus minutus* did not produce as much mycelium in a dextrose solution culture medium as *Aspergillus luchuensis*. However, *Aspergillus minutus* contained a larger percentage of phosphorus and assimilated more phosphorus than *Aspergillus luchuensis*.

The results reported in this paper were obtained in a further study of the activities of molds in certain Iowa soils, determining their phosphorus assimilating power.

EXPERIMENTAL PROCEDURE

Aspergillus niger and *Cunninghamella* sp. were selected for the study since the growth of these two molds has been used as a measure of available phosphorus in soils. A medium containing 1% dextrose, 0.5% peptone, 0.05% $MgSO_4 \cdot 7H_2O$, 0.1% $NaNO_3$, and 0.1% K_2SO_4, and referred to as dextrose medium A, was used for comparison with the medium recommended by Niklas, *et al.* (2). A medium similar to dextrose medium A, except that it contained 10% dextrose, was also used and is referred to as dextrose medium B. Varying amounts of the different phosphates were added to the phosphorus-free media as shown in the different experiments.

The media were placed in wide-mouth extraction flasks for inoculation and growth of the molds. In all cases, except where otherwise stated, 60 cc of the

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[2] Associate Professor, Professor, and Fellow, respectively.

[3] Figures in parenthesis refer to "Literature Cited", p. 1000.

medium were placed in 150-cc flasks and 1 cc suspensions of young spores were used for inoculation. The spore suspensions were prepared by inoculating 50 cc of the medium containing 200 p.p.m. of phosphorus in extraction flasks and incubating 6 to 10 days at 35°C. The excess medium was drained from the flask and the mycelium rinsed twice with small amounts of distilled water. A small amount of distilled water was added, and the flask stoppered and shaken vigorously to dislodge the spores. The contents of the flask were then emptied on a screen placed over a funnel and the spores washed into a 500-cc Erlenmeyer flask with distilled water. The spore suspension was made up to 200 cc.

Four flasks in each treatment were inoculated, except in one case where six relpicate cultures were inoculated. The cultures were incubated 5 to 6 days at 35°C. The mycelium was removed at the end of the incubation period, washed, dried, and weighed according to the procedure outlined by Niklas, *et al.* (2).

RESULTS

I. WEIGHT AND PHOSPHORUS CONTENT OF MYCELIUM GROWN ON DIFFERENT MEDIA

Phosphorus additions were made as $CaH_4(PO_4)_2.H_2O$ in the amounts of 0, 0.246, 2.46, 24.6, 246, 492, 738, 984, 1,230, and 1,476 p.p.m. to the Niklas medium and to dextrose medium A. Fifty cc of the media were placed in 250-cc extraction flasks. Six flasks were prepared for each concentration of phosphorus. There were two series of flasks for each medium, the one being inoculated with *Aspergillus niger* and the other with *Cunninghamella* sp. The cultures were incubated 5 days. The phosphorus content of the mycelium was determined by the official method. The results obtained are presented in Tables 1 and 2 and in Figs. 1, 2, and 3.

Cunninghamella sp. did not make any appreciable growth in the Niklas medium. No mycelium was produced by *Aspergillus niger* in the phosphorus-free Niklas medium. The weight of mycelium in the replicate cultures varied considerably, especially at the lower concentrations of phosphorus. However, the mean weights of mycelium of the six cultures varied significantly and were almost proportional to the amount of phosphorus in the medium. This relation between the weight of mycelium and the concentration of phosphorus in the medium did not hold above about 500 p.p.m. of phosphorus, although the percentage of phosphorus in the mycelium continued to increase.

The curve for the *Aspergillus niger* in the Niklas medium (Fig. 1) up to about 500 p.p.m. of phosphorus is a typical exponential curve as evidenced in the straight line obtained when the logarithm of the weight of mycelium is plotted against the logarithm of the concentration of phosphorus in the mycelium (Fig. 2).

There was considerable growth of both molds in dextrose medium A, to which no phosphorus had been added. Apparently the peptone added in this medium contained some phosphorus available to these molds. The weight of mycelium was almost proportional to the amount of phosphorus in the medium at the lower concentrations of phosphorus, but an increase in the concentration of phosphorus did not bring about a corresponding increase in the weight of mycelium at the higher concentrations of phosphorus. In dextrose medium B,

TABLE I.—*Weight and phosphorus content of mycelium of A. niger and Cunninghamella sp. grown in various media.*

Culture No.	Mgm phosphorus in 100 cc. of medium																			
	0		0.0123		0.1230		1.230		12.30		24.6		36.9		49.2		61.5		73.8	
	A*	B*	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B
A. niger in Niklas' Medium																				
1	0	0	24	0.3638	72	0.3908	402	0.6737	1161	3.045	1414	5.174	1388	5.309	1322	5.174	1340	8.188	1480	20.12
2	0	0	33	0.3301	68	0.3099	355	0.6602	1135	2.937	1425	4.648	1330	5.282	1332	5.498	1359	9.029	1334	11.09
3	0	0	26	0.2707	57	0.4160	383	0.5928	1209	3.012	1420	4.635	1372	5.371	1355	5.484	1346	7.666	1373	12.98
4	0	0	41	0.3908	79	0.4042	272	0.6330	1198	2.964	1433	5.012	1389	5.552	1361	6.333	1345	8.409	1338	—
5	0	0	35	0.2916	56	0.1348	411	0.7264	1143	3.045	1414	4.298	1393	5.659	1375	6.576	1342	8.100	1340	—
6	0	0	31	0.3368	41	0.4582	339	0.6871	1155	2.924	1416	4.730	1393	5.552	1364	5.012	1343	—	1337	—
Average	0	0	33.3	0.3306	62.2	0.3523	360.6	0.6622	1166.8	2.9878	1420.3	4.7495	1377.5	5.4541	1351.6	5.7128	1345.8	8.2784	1367	14.73
A. niger in Dextrose Medium A																				
1	159	0.1212	169	0.1074	189	0.2289	134	0.9025	156	1.536	238	2.412	240	2.553	212	2.614	258	4.231	241	3.726
2	151	0.0939	174	0.1210	193	0.2424	162	0.9968	157	1.644	226	2.492	230	2.830	217	2.422	221	3.112	195	3.274
3	152	0.0939	165	0.1074	185	0.2289	158	0.9768	161	1.657	242	3.227	226	2.654	206	3.112	228	3.450	225	2.802
4	153	0.1074	172	0.1206	189	0.2289	150	0.9968	171	1.832	243	2.480	242	2.897	225	2.776	257	4.918	248	4.002
5	—	—	165	0.1074	190	0.2289	148	0.9431	171	1.832	267	2.715	220	2.546	221	2.735	226	3.638	231	3.194
6	—	—	176	0.1074	196	0.2560	161	0.9780	159	1.684	240	2.156	219	2.480	254	3.610	213	3.938	196	2.856
Average	153.7	0.1041	170.1	0.1118	190.3	0.2356	152.1	0.9656	162.5	1.697	242.6	2.280	229.5	2.615	222.5	2.878	233.8	3.881	222.6	3.309
Cunninghamella sp. in Dextrose Medium A																				
1	97	0.2964	113	0.3098	97	0.3368	102	0.9698	160	3.610	211	5.127	222	5.228	234	6.023	221	6.454	219	6.980
2	98	0.2964	99	0.3098	102	0.3503	142	0.9698	162	4.689	219	5.160	229	5.511	227	6.252	237	6.238	216	6.684
3	105	0.2964	88	0.3098	92	0.3634	86	0.9296	123	1.940	235	5.080	240	5.646	216	5.820	223	6.050	227	6.600
4	91	0.2964	95	0.3098	91	0.3770	109	0.8890	165	4.230	219	4.833	222	5.652	223	5.870	216	6.320	215	6.171
5	—	—	89	0.3098	100	0.3970	113	0.8890	153	6.638	231	5.160	218	5.713	224	5.734	217	5.619	221	6.172
6	—	—	109	0.3098	96	0.3970	99	0.8890	167	3.604	221	4.952	217	5.592	224	5.895	203	5.821	223	6.333
Average	97.7	0.2964	98.8	0.3098	98	0.3686	108.5	0.9227	155	4.118	222.6	5.052	224.6	5.557	224.6	5.932	219.5	6.084	220.1	6.490

*"A" columns are weight of mycelium; "B" columns, weight of phosphorus in mycelium.

similar to dextrose medium A except that it contained 10% of dextrose, the weight of mycelium was materially increased at the higher concentrations of phosphorus (Table 2).

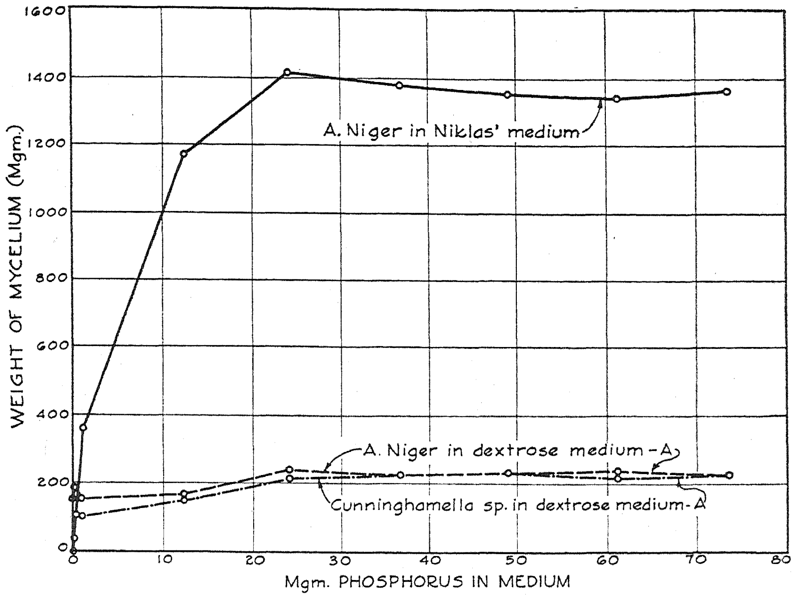

FIG. 1.—The influence of phosphorus on the weight of mycelium of *Aspergillus niger* and *Cunninghamella* sp. in different media.

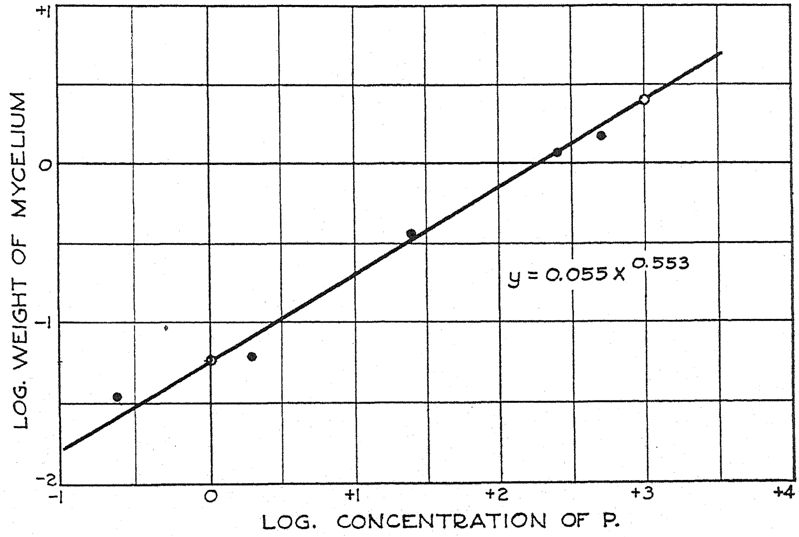

FIG. 2.—Relation of weight of *Aspergillus niger* mycelium to concentration of phosphorus in Niklas medium.

TABLE 2.—*Weight and phosphorus content of A. niger and Cunninghamella mycelium grown in dextrose medium B.*

Culture No.	Mgm phosphorus in medium							
	A. niger				*Cunninghamella* sp.			
	12.3		24.6		12.3		24.6	
	A*	B*	A	B	A	B	A	B
1..........	746	——	860	6.373	532	3.934	561	8.448
2..........	705	3.557	842	5.659	669	3.800	571	7.600
3..........	801	3.826	790	6.063	——		——	
Average	750.6	3.691	830.6	6.031	600.5	3.867	566.0	8.024

*"A" columns are, weight of mycelium; "B" columns, weight of phosphorus in mycelium.

Analysis of the data shows that the amount of phosphorus in the *Aspergillus niger* mycelium was not significantly correlated with the weight of mycelium in the replicate cultures, but the correlation was highly significant between the means of the six cultures at the different concentrations of phosphorus.

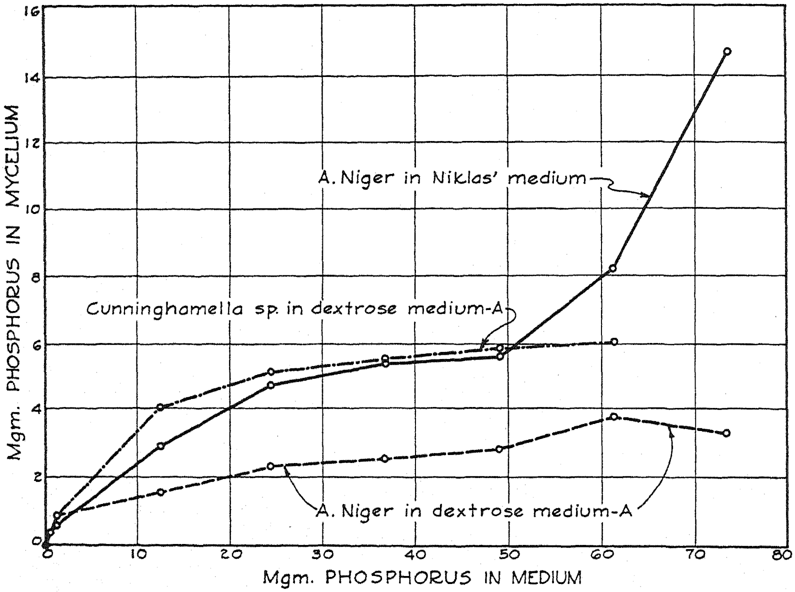

FIG. 3.—The assimilation of phosphorus by *Aspergillus niger* and *Cunninghamella* sp.

2. RELATION OF WEIGHT OF *Aspergillus niger* MYCELIUM TO CONCENTRATION OF PHOSPHORUS IN MEDIUM

The data obtained in the preceding experiment indicated that the weight of mycelium was a function of the concentration of phosphorus in the medium at concentrations of phosphorus below about 500 p.p.m. Since soils containing more than 500 p. p. m. of available phosphorus would be unlikely to show a need for phosphate fertilizers, the weight of *Aspergillus niger* mycelium might indicate the needs of the soil for phosphorus if the relation between the weight of mycelium and phosphorus content were better known.

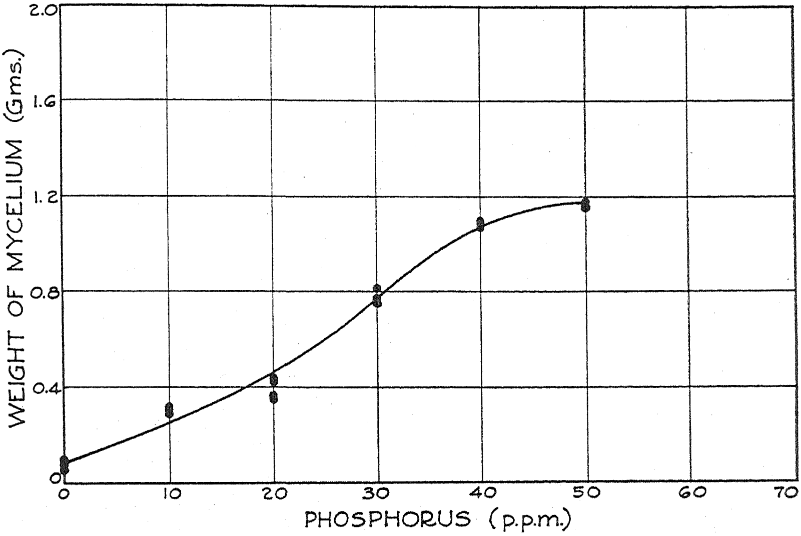

FIG. 4.—Relation of weight of *Aspergillus niger* mycelium to concentration of phosphorus in the medium.

In order to get more information about this relationship, *Aspergillus niger* was grown in varying concentrations of phosphorus and the weight of mycelium determined.

The concentration of phosphorus was varied at intervals of 10 p.p.m. up to 50 p.p.m. Four flasks of the Niklas medium were prepared for each concentration of phosphorus and inoculated with *Aspergillus niger* spores. After incubation the mycelium was dried and weighed. The results obtained are presented in Fig. 4.

The data show that as the concentration of phosphorus increased the weight of mycelium also increased, but the relationship was not the same as in the first experiment. There was a considerable growth of the mold in the phosphorus-free medium, and at 10 p.p.m. of phosphorus the weight of mycelium was 320 mgm. The two experiments were conducted in the same manner, except that the inoculum for the second experiment was from a different batch of spores. The age of the spores used for inoculation was about the same in both cases, but there was no check on the approximate number of spores carried in the 1 cc used for inoculation in the two experiments.

3. RELATION BETWEEN SIZE OF INOCULUM TO WEIGHT OF *Aspergillus niger* MYCELIUM

The influence of size of inoculum on the weight of mycelium was determined in an experiment using 0.1-, 0.5-, 1.0-, 2.0-, and 5.0- cc spore suspensions for inoculation. Two hundred p.p.m. of phosphorus as $CaH_4(PO_4)_2.H_2O$ were added to 60 cc of the Niklas phosphorus-free medium. Four flasks with each inoculation were incubated and the weight of mycelium determined as in the above experiments. The results obtained are shown in Fig. 5.

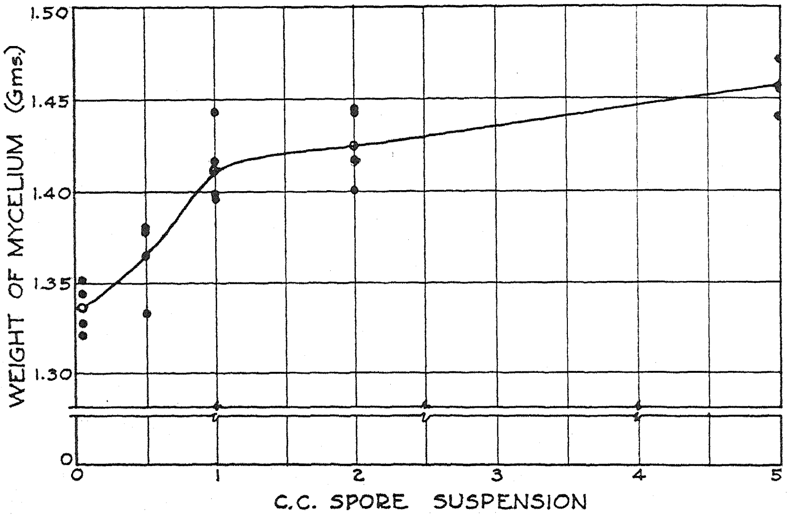

FIG. 5.—Effect of size of inoculum on weight of mycelium.

The data show that there was a rather sharp increase in the weight of mycelium with an increase in the size of inoculum up to 1.0 cc. There was also a small average increase in the weight of mycelium with an increase in the size of inoculum above 1.0 cc. These results undoubtedly explain the variation in weight of mycelium of replicate cultures.

4. RELATION BETWEEN WEIGHT OF MYCELIUM AND CONCENTRATION OF PHOSPHORUS IN SOIL

Additions of phosphorus as $CaH_4(PO_4)_2.H_2O$ to 3.5 grams of soil were made to determine the influence of the soil in the medium on the relationship between the weight of mycelium to concentration of phosphorus. The concentration of phosphorus was varied at intervals of 10 p.p.m. up to 100 p.p.m. Four flasks for each concentration of phosphorus were inoculated, incubated, and the weight of mycelium determined. The results obtained are presented in Figs. 6 and 7.

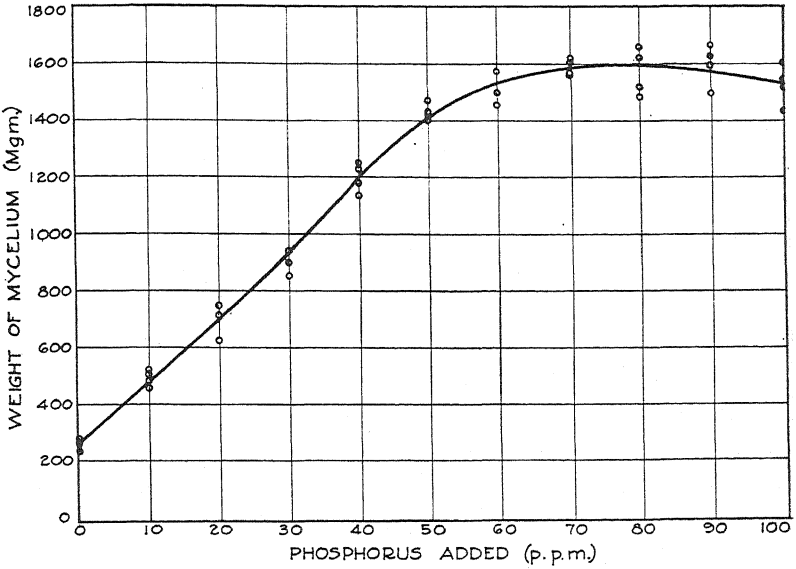

FIG. 6.—Effect of soil and phosphorus on the weight of *Aspergillus niger* mycelium.

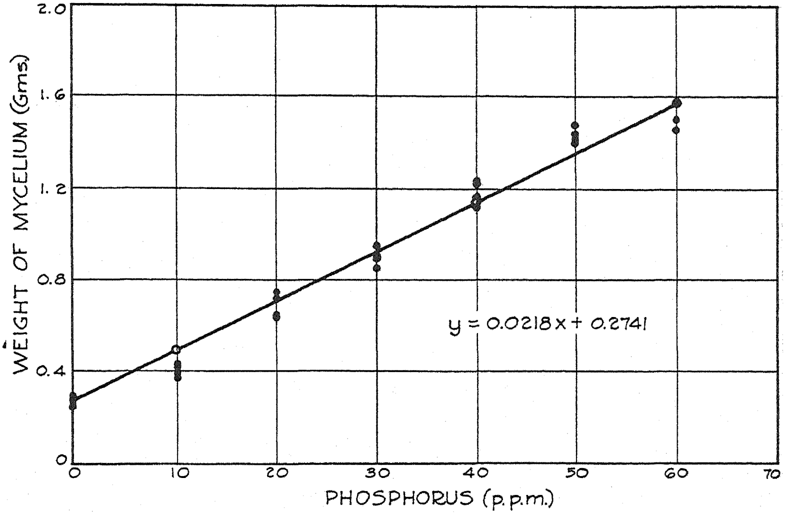

FIG. 7.—Relation of weight of *Aspergillus niger* mycelium to concentration of phosphorus in soil medium.

The data show that the weight of mycelium increased directly as the concentration of phosphorus increased up to about 60 p.p.m. of phosphorus. Plotting the weight of mycelium against the concentration of phosphorus in the range 0 to 60 p.p.m. of phosphorus gives a fairly straight line (Fig. 7).

5. RELATION BETWEEN WEIGHT OF MYCELIUM AND AMOUNT OF SOIL IN MEDIUM

The addition of soil to the medium in the preceding experiment brought about a different relationship between the weight of mycelium and the concentration of phosphorus than was obtained when the mycelium was grown in a soil-free medium. In this experiment

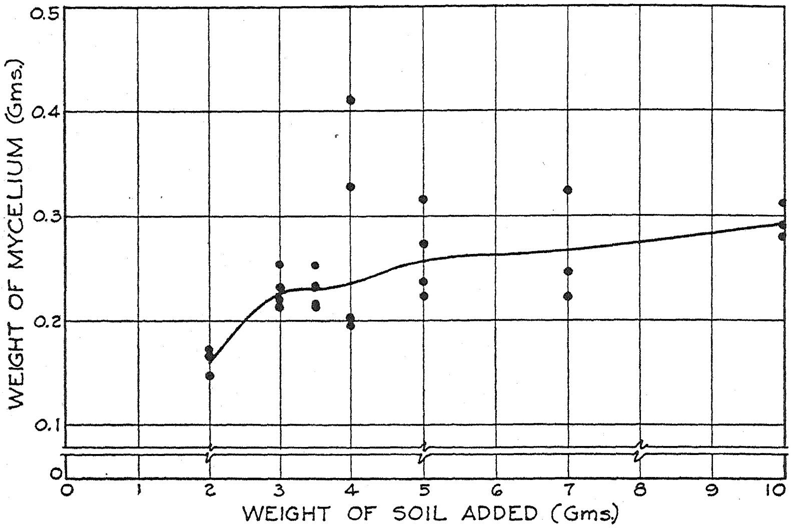

FIG. 8.—Effect of soil added to medium on the weight of *Aspergillus niger* mycelium.

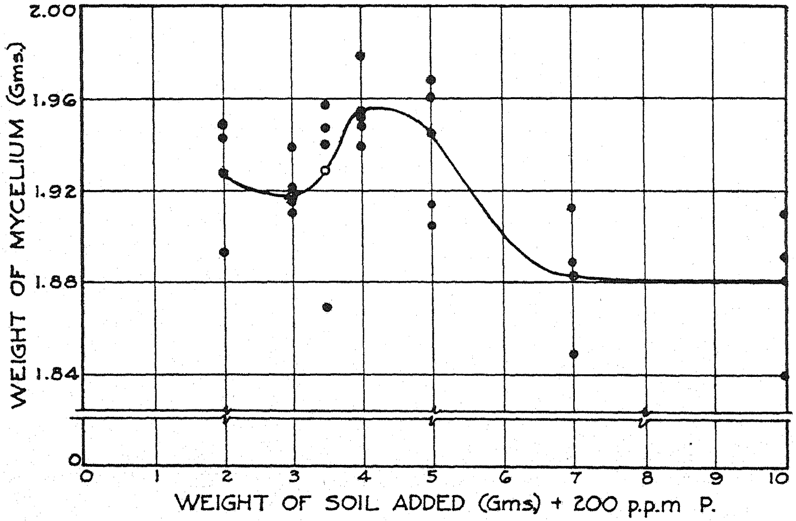

FIG. 9.—Effect of soil and phosphorus added to medium on the weight of *Aspergillus niger* mycelium.

different amounts of soil were added to a phosphorus-free medium in one series and the same amounts of soil added to the medium in another series which contained 200 p.p.m. of phosphorus. The results obtained are shown in Figs. 8 and 9.

A small average increase in the weight of mycelium was obtained with an increase in the amount of soil added up to 4 grams of soil, where no phosphorus was added in addition to that contained in the soil (Fig. 8). There was a considerable variation in the weight of mycelium in the replicate cultures above 3.5 grams of soil added where 200 p.p.m. of phosphorus were added in addition to the soil. The highest average weight of mycelium was obtained at 4 grams of soil but the weight of mycelium of three of the four cultures at 3.5 grams of soil averaged as much as the weight of mycelium at 4 grams. With an increase in the amount of soil added where phosphorus was also added (Fig. 9), there was a tendency for the weight of mycelium to decrease. This was probably brought about by a fixation of phosphorus by the soil or by the activity of other micro-organisms.

6. RELATION BETWEEN VOLUME OF MEDIUM TO WEIGHT OF MYCELIUM

The influence of volume of medium on the weight of mycelium was determined by inoculating flasks containing 30, 60, 90, 120, 150, and 180 cc of the phosphorus-free medium to which 3.5 grams of soil had been added. The weight of mycelium was determined after 6 days incubation. The curve (Fig. 10) is drawn through the average weights of the four replicate cultures.

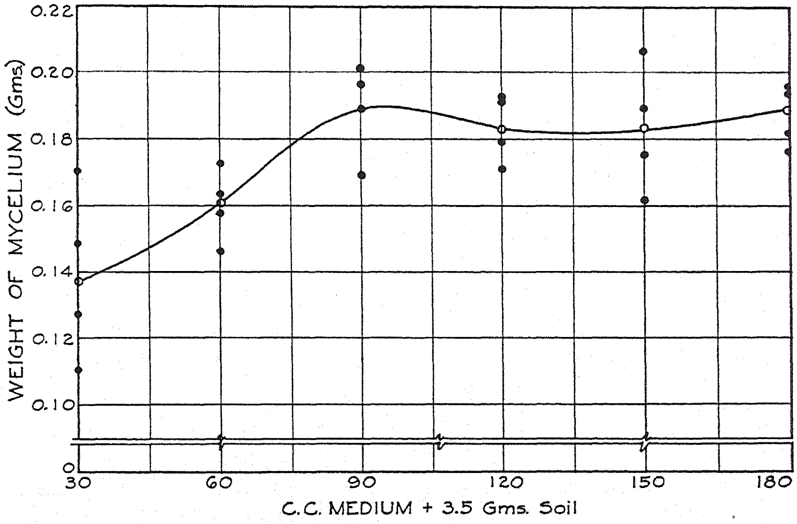

FIG. 10.—Effect of volume of medium on the weight of *Aspergillus niger* mycelium.

The data show quite a variation in the weight of individual pads, but the average weight of mycelium increased with an increase in the volume of medium up to 90 cc. There was a slight decrease in the weight of mycelium with 120 cc and 150 cc of medium over that obtained with 90 cc of medium.

7. WEIGHT OF MYCELIUM FROM DIFFERENT FORMS OF PHOSPHATE

The relationship between the weight of mycelium and the concentration of phosphorus was different in the soil-free medium than when soil was added. This change in relationship may be due in part to the addition of forms of phosphorus in soil other than mono-calcium phosphate which was used in the soil-free medium. A series of flasks were inoculated which contained 200 p.p.m. of phosphorus supplied by different common soil phosphates. After incubation the weight of mycelium was determined and the average weight of the four replicate cultures given for each phosphate (Fig. 11).

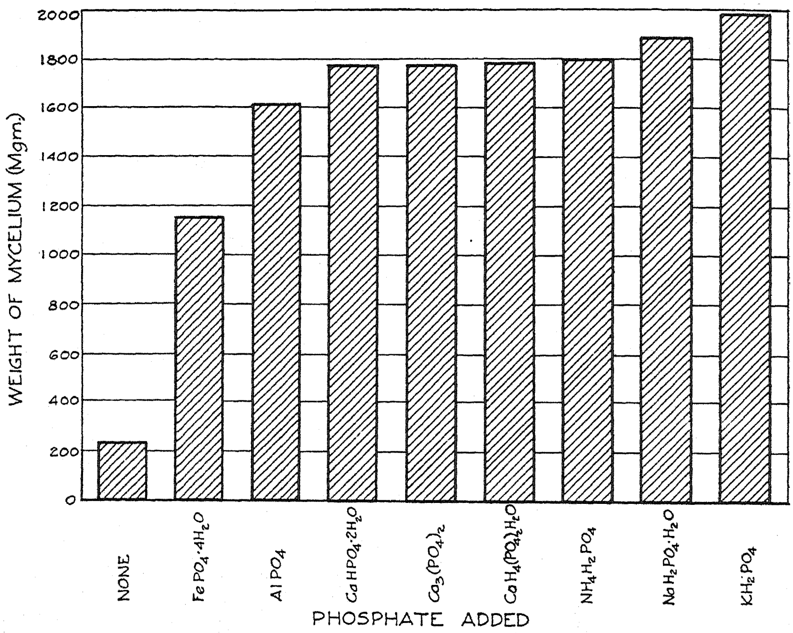

FIG. 11.—The weight of *Aspergillus niger* mycelium grown on different phosphates.

The average weight of mycelium was about the same for the three calcium phosphates. The average weight of mycelium was increased slightly in the ammonium, sodium, and potassium phosphates, respectively, over that obtained with calcium phosphates. The weight of mycelium obtained with iron and aluminum phosphates was decreased under that obtained with the calcium phosphates. These differences were probably caused by a difference in the solubility of the different phosphates or to the effect of the different cations on the growth of the mold.

DISCUSSION OF RESULTS

The amount of phosphorus taken up by *Aspergillus niger* and *Cunninghamella* sp. increased with increasing concentrations of phosphorus in the medium, but the variation between the amount of phosphorus assimilated by duplicate cultures was large and not significantly correlated with the weight of mycelium. The Niklas medium was more favorable for the growth of *Aspergillus niger* than a dextrose-peptone medium, but *Cunninghamella* sp. did not make a satisfactory growth in the Niklas medium.

The relationship between the weight of *Aspergillus niger* mycelium in the Niklas medium over a range in phosphorus concentration from 0 to 500 p.p.m. was represented by an exponential curve. However, a different type of curve was obtained when the experiment was repeated to obtain a larger number of points on the curve over a smaller range of concentrations of phosphorus. The chief reasons for the variations in the relationship of weight of mycelium to the concentration of phosphorus in the medium in the different experiments were undoubtedly a difference in the number of spores used for inoculation, the viability and the efficiency of the spores used, the volume of medium, and the length of incubation period, as well as the natural variation between cultures of the same organism. That all of these factors were important in determining the weight of mycelium in a given concentration of phosphorus was demonstrated in several experiments.

A different relationship between the weight of mycelium and the concentration of phosphorus was obtained when soil was added to the medium than when a soil-free medium was used. In the presence of the soil used, Carrington loam, the weight of mycelium obtained was directly proportional to the amount of phosphorus present in the medium over the range from 0 to about 60 p.p.m. of phosphorus. This relationship was characteristic of Carrington loam under the conditions of the experiment. That the above relation would vary with different soils is emphasized by the results obtained when different forms of phosphate were used and that it would vary with the same soil under different conditions is brought out by the results obtained by varying the amount of soil added or the volume of medium employed.

The results of these experiments show that the growth of *Aspergillus niger* in the Niklas medium to which soil has been added may be used to indicate roughly the amount of phosphorus available to *Aspergillus niger*, but that any attempt to interpret the results of such tests as showing quantitatively the amount of available phosphorus in the soil is likely to lead to erroneous conclusions. It may serve as a qualitative test if the technic employed is carefully standardized. For the soil used in these experiments 4 grams of soil in 90 cc of medium in a 250-cc extraction flask with a 1 cc suspension of spores 6 to 10 days old for incubation and an incubation period of 6 days seemed most satisfactory.

SUMMARY AND CONCLUSIONS

Experiments were conducted in a study of phosphorus assimilation by *Aspergillus niger* and *Cunninghamella* sp. to determine the relationship of the weight of mycelium to the concentration of phosphorus in the medium. It was found that the weight of *Aspergillus niger* mycelium in Niklas medium to which soil was added was roughly proportional to the concentration of phosphorus in the medium over the range from 0 to about 60 p.p.m. of phosphorus.

It was concluded that the weight of *Aspergillus niger* mycelium in the Niklas medium to which soil has been added may be used to indicate roughly the amount of phosphorus available to *Aspergillus niger* if the technic employed is carefully standardized. Whether or not the phosphorus available to *Aspergillus niger* represents the amount of phosphorus available to crop plants was not determined.

LITERATURE CITED

1. KOSZELECKI, A. K. Die Bestimmung der phosphorsäure in Lösungen mittels der Kultur von *Aspergillus niger*. Zhur. opytn. Agron., 10: 321–354. Abs. Zeitschr. Pflanzenernähr. Dung. u. Bodenk. A, 24: 341–342. 1909.
2. NIKLAS, H., POSCHENRIEDER, H., and TRISCHLER, J. Die Kultur des Schimmelpilzes *Aspergillus niger* zur biochemischen Bestimmung der Kali-u. phosphorsäuredüngebedürftigkeit der Böden. Die Ernährung Der Pflanze, 26: 97–103. 1930.
3. SIMAKOVA, T., und BOVSCHIK, G. Ueber die mikrobiologische methode zur Bestimmung des phosphorbedürfnisses des Bodens mittels *Aspergillus niger*. Zeitschr. f. Pflanzenernähr. Dung. u. Bodenk. A, 24: 341–353. 1932.
4. THOMPSON, L. G., JR., and SMITH, F. B. The effect of phosphorus on nitrogen fixation by Azotobacter. Ia. Acad. Sci. Proc., 38: 299–302. 1931.
5. THOMPSON, L. G., JR., SMITH, F. B., and BROWN, P. E. Phosphorus assimilation by soil microorganisms. Soil Science, 31: 431–436. 1931.

REGISTRATION OF VARIETIES AND STRAINS OF OATS, VII[1]

T. R. STANTON[2]

THE sixth report on the registration of improved oat varieties was submitted in 1934 and published in January, 1935.[3] Only one improved strain of oats, a winter variety, was submitted and approved for registration in 1935. It is as follows:

Group and Varietal Name	Reg. No.
Midseason gray:	
Support	83

A summary of the available information on description, performance, and potential value of this new variety, on which approval for registration is based, is given in the following paragraphs:

Support (C. I. No. 3180) was originated in 1926 as a plant selection known as "Number 5" from unlabeled plant material at the Oregon Agricultural Experiment Station, Corvallis, Ore., by H. A. Schoth.[4] So far it has not been possible to determine whether this selection arose from unfixed hybrid material furnished by the Division of Cereal Crops and Diseases from the Arlington Experiment Farm, Rosslyn, Va., to E. N. Bressman, formerly of the Oregon Agricultural Experiment Station, in the falls of 1924 and 1925, or from stocks grown previous to 1924 at Corvallis by C. C. Ruth. Strain No. 5 was subsequently developed and multiplied by H. A. Schoth, who applied for its registration. Support was first distributed to farmers in 1931.

Support is a midtall to tall, midseason, gray-seeded winter common oat similar to Winter Turf (Oregon Gray). The superior characters of Support are high yield, stiff straw, thin hull, heavy stooling, and rust-evasion in western Oregon. Under the conditions at Corvallis, Support is about 10 days earlier than Winter Turf and is an excellent support crop for annual viny legumes such as vetch. The writer observed Support grown in nursery rows this past season at the Arlington Experiment Farm and at the Aberdeen Substation, Aberdeen, Idaho, from fall and spring seeding, respectively. Support is undoubtedly very similar to Winter Turf, yet there is a difference in the color of the straw and general appearance of the plant during the ripening period that distinguishes it from the older variety. At Aberdeen, Idaho, Support ripened fully 6 days in advance of Winter Turf and developed a more distinct grayish lemma. At the Arlington Exper-

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[1] Registered under cooperative agreement between the Bureau of Plant Industry, U. S. Dept. of Agriculture, and the American Society of Agronomy. Received for publication November 26, 1935.

[2] Senior Agronomist in Charge of Oat Investigations, Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture. Member of the 1935 Committee on Varietal Standardization and Registration, charged with the registration of oat varieties.

[3] STANTON, T. R. Registration of varieties and strains of oats, VI. Jour. Amer. Soc. Agron., 27: 66–70. 1935.

[4] Associate Agronomist, Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture.

iment Farm it ripened only 2 days ahead of the earlier Winter Turf strains and appeared to be about equally winter resistant. At the former station, Support thus showed some evidence of being of hybrid origin, while at the latter it appeared simply to be an early strain of Winter Turf.

Support was tested in duplicated 1/20 acre plats from 1927 to 1931 at Corvallis. The annual and average acre yields of Support and Winter Turf, the standard winter oat of western Oregon and Washington, are given in Table 1.

TABLE 1.—*Annual and average acre yields of Support and Winter Turf (Oregon Gray) winter oat varieties grown at the Oregon Experiment Station, Corvallis, Ore., 1927–31.*

Variety	Acre yield, bushels					
	1927	1928	1929	1930	1931	Average
Support	61.9	85.0	88.1	79.4	81.3	79.1
Winter Turf	66.1	64.6	72.6	65.9	65.4	66.9

Interest in Support is rapidly increasing among farmers in western Oregon where fall-sown oats are relatively important. Mr. H. A. Schoth, in a letter addressed to the writer under date of September 4, 1935, reports on Support as follows: "There was a considerable acreage of this oat grown in western Oregon this year. There was also a smaller acreage grown in western Washington. Crops in each case were reported as being very good and the quality of the grain as excellent."

BOOK REVIEWS

TRANSACTIONS OF THE THIRD INTERNATIONAL CONGRESS OF SOIL SCIENCE

Vol. I. Commission Papers. XII + 428 pages, illus. 1935. Vol. II. Plenary Session Papers and Presidential Address. VI + 194 pages, illus. 1935. London: Thomas Murby & Co.

THESE two volumes, together with a third which is not yet available, make up the report of the transactions of the Third International Congress of Soil Science. Although they represent the customary report which follows each Congress, there are a number of important and desirable changes in general form.

Volume I contains the papers presented before the various Commissions of the Congress. The papers, 156 in number, are classified and arranged with reference to specific subjects under each of the nine Commissions and Sub-commissions. The table of contents shows the papers to be arranged under 30 different general subjects, consecutively as to Commissions and alphabetically as to the contributors to these subjects. This arrangement makes it almost as easy to find specific authors or subjects as if the volume were regularly indexed.

Volume II contains the Presidential address and the plenary session papers of the various Commissions. These include 15 complete papers or from two to three for each of the six Commissions. In both volumes, the papers of the German and French contributors are printed in those languages, while all others are in English.

These two volumes, together with the third one of the report, should give the worker in the various fields of soil science an excellent picture not only of what other soil workers are doing, but also what they are thinking in this important and fundamental branch of science. (R. C. C.)

THE USE AND MISUSE OF LAND

By R. Maclagan Gorrie. New York: Oxford University Press (Oxford Forestry Mem. No. 19). 80 pages, illus. 1935. $2.00.

IN these days when so much attention is being centered on soil conservation, this book should be of unusual interest. The author, through the generosity of a Leverhulme Research Fund, was able to make a four months' tour of the United States. The original purpose was to study the influence of grazing upon soil erosion. The report, however, deals with a much broader field, including several other abuses of both forest and farm lands. The survey was conducted largely in the western states and, therefore, the conclusions are largely applicable to that area.

An idea of the scope of the book can be secured by noting the eight main chapter headings which are as follows: I. Forestry as a Factor in Land Management; II. Grazing and Range Management; III. Over-grazing as a Primary Cause of Soil Erosion; IV. Value of Vegetational Cover in Stream Flow Control; V. Forestry as a Factor in Farm and Village Economy; VI. Farm Erosion and Its Control; VII. Other Examples of the Misuse of Land; and VIII. Public and Private Control of Land.

The book contains descriptions of many recent soil erosion investigations and presents many actual data secured as a result of these investigations. Also, the writer gives his ideas as to possible ways of cutting down the serious erosion losses which occur on mismanaged lands.

The book should be of equal value to those interested in soil erosion research and to those concerned primarily with the broader aspects of land management policies. (R. F. C., Jr.)

THE DESIGN OF EXPERIMENTS

By B. A. Fisher. Edinburgh: Oliver and Boyd. IX + 252 pages, illus. 12/6 net. 1935.

THIS new book by Dr. Fisher brings together in one volume most of the later studies in experimental technic which have been developed by himself and other workers. In it, the author emphasizes particularly the fundamental principles of experimental design with the aim of making the use of analysis of variance applicable to the data. The book is not a review of technic used by other workers, nor does it consist of a collection of diagrams of plat arrangement, although numerous illustrative examples are given. It is rather difficult in a brief review to give a comprehensive account of the vast amount of information that is condensed in this work. Perhaps most readers will get a better idea of the scope of the work from a listing of the chapter headings and brief discussions of these than from more general statements.

The introductory chapter deals largely with the logic of inductive inference. In Chapter II, entitled "The Principles of Experimentation Illustrated by a Psycho-physical Experiment", there are considered the test of significance, the null hypothesis, randomization, etc. Chapter III is devoted to a description of Darwin's experiments in cross- and self-fertilization of plants, together with various interpretations of the data. Chapter IV is entitled "Agricultural Experiment in Randomized Blocks" and in it are discussed the general principles of plat arrangement and statistical analysis of the observations. "The Latin Square" is the title of Chapter V in which are considered, among other subjects, faulty treatment of square designs, systematic squares, and Graeco-Latin and higher squares.

"The Factorial Design in Experimentation" (Chapter VI) should prove of considerable interest to those workers who, because of the number of tests, are either unable to make many replications or who desire to get the most out of field tests that have few or even no replications. Chapter VII, "Confounding" is an extension of the factorial scheme, while Chapter VIII considers "Special Cases of Partial Confounding". "The Increase of Precision by Concomitant Measurement, Statistical Control" (Chapter IX) is a discussion of suitable occasions for concomitant measurements, arbitrary correction, and the test of significance. Chapter X, "Generalization of Null Hypotheses, Fiducal Probability" is concerned with various tests, such as the *t* test, the X^2 test, and wider tests based on the analysis of variance. Chapter XI, "The Measurement of Amount of Information in General" places in a brief space consideration of the following subjects: Estimation in general, frequencies of two alternatives, functional relationships among parameters, the frequency ratio in biological assay, linkage values inferred from frequency ratios and from the progeny of self-fertilized or inter-crossed heterozygotes, information as to linkage derived from human families, information elicited by different methods of estimation, and information lost in the estimation of error. Numerous practical examples are given throughout the book.

It is difficult to see how any investigator, and especially those workers who deal with agricultural experiments, can fail to find a wealth of information and assistance in this unique work. It should be on the desk of every worker. (F. Z. H.)

DICTIONARY OF TERMS

By T. J. Bezemer. Baltimore: Williams & Wilkins Co. VII + 1062 pages. 1935. $8.

TO say that this book is unique is to state the obvious when one considers that it is an attempt to bring together in one volume a list of English, French, Dutch, and German terms commonly used in general agriculture, horticulture, forestry, cattle breeding, and dairying as an aid to the student in finding exact equivalents of technical terms encountered in foreign textbooks and works of reference. The fact that American workers will have their curiosity aroused at once as to the basis for the selection of the terms listed in the volume does not detract in the least from the value of the work with respect to the terms that are included. The compiler makes no claim to completeness and points out that preference has been given to those terms believed to have the greatest importance in their particular field. For example, it is stated that to name all of the useful and injurious insects would require a volume in itself, hence in the present work will be found "only those which are most important for agriculture in the widest sense of the term".

The volume has been compiled by Professor Bezemer with the assistance of several of his colleagues at the State Agricultural College at Wageningen, Holland, and is divided into four parts, *viz.*, English, Dutch, French, and German. This enables the user when employing any one of these languages to find the equivalents of the term in the three other languages. For example, under "Wheat" in the English section, one finds the following entry:

wheat.—Weizen *m.*—**tarwe** *f.*—**froment** *m.*, **blé** *m.* (*Triticum* **sp.**)

One might question the use of the word "Dictionary" in connection with such a volume, which would be more exactly described as a "Glossary", since no attempt is made to trace the derivation of the terms or to define them. This is of minor importance, however, so long as one understands the purpose and content of the volume. Certainly it will prove an invaluable aid to the abstractor, to the librarian, and to everyone in fact who reads extensively in the agricultural literature of these four languages. (J. D. L.)

ERGEBNISSE DER AGRIKULTURCHEMIE

By F. Alton and M. Trénel. Berlin: Verlag Chemie, G. M. B. H. 156 pages, illus. 1935. RM 8.

THIS is Volume 3 of the proceedings of the 47th Congress of the Verein Deutscher Chemiker in Köln in 1934. It contains a general article by H. Niklas on the rôle of agricultural chemistry in the new Germany and three groups of papers on soils and fertilizers, animal nutrition, and agricultural technology. Most of the articles are reviews rather than presentation of new data.

The field of soil chemistry in relation to the determination of nutrient requirements is discussed in several papers. The article of R. Thun on the organization and work of the small experimental cooperative organizations (Versuchsringe) will be of general interest to agronomists because of the success of these establishments in Europe.

Other articles on soils and fertilizers are from F. Alton, W. U. Behrens, Trénel and Alton, L. Schmidtt, and C. Pfaff. The articles on animal nutrition are by A. Scheunert, A. Jacob, L. Seidler, and W. Wöhlbier. The problem of sugar production from wood and its utilization as feed is discussed by Spengler und H. Claassen.

The reader of this volume obtains a good cross-section of the present position and future problems of practical agricultural chemistry in Germany. (Z. I. K.)

FELLOWS ELECT

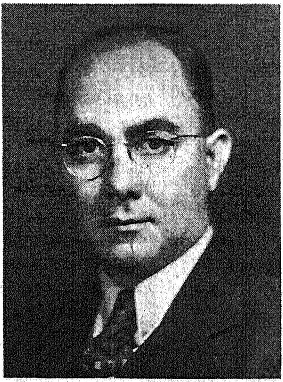
ALBERT CEDRIC ARNY

ALBERT CEDRIC ARNY, College of Agriculture, University of Minnesota, St. Paul, Minnesota. Born at Newport, Minnesota, November 4, 1877. B.S.A., University of Minnesota 1909; M.S., University of Minnesota 1918. Assistant Professor of Agronomy, University of Minnesota 1909–1916; In Charge of Farm Crops Section, Division of Farm Management, Agronomy, and Plant Genetics, 1914–1927; Associate Professor of Agronomy and Associate Agronomist, 1916—.

Member of American Society of Agronomy; Minnesota Academy of Science. While his special interests include crop rotations, forage crops, weed eradication, and flax breeding, he is also greatly interested in all other phases of agronomic work as shown by numerous publications.

Professor Arny has been a member of the Society for many years, has been a member of several standing committees, and was chairman of the Committee on Intercollegiate Crop Judging Contests.

RICHARD BRADFIELD



RICHARD BRADFIELD, Ohio State University, Columbus, Ohio. Born on a farm near West Jefferson, Madison County, Ohio, April 29, 1896, where his family were some of the pioneer settlers of the county. B.A., Otterbein College, Westerville, Ohio, 1917; Ph.D., Ohio State University, 1922. Instructor in Soils, University of Missouri, 1920–1922; Assistant Professor of Soils, 1922–1923; Associate Professor 1923–1930; Guggenheim Fellow, Kaiser Wilhelm Institute, Berlin, Germany, 1927–1928; Professor of Agronomy, Ohio State University 1930—; Associate in Agronomy, Ohio Agricultural Experiment Station, 1930—.

Member A.A.A.S.; American Society of Agronomy; American Soil Survey Association; International Society of Soil Science; American Chemical Society; Ohio Academy of Science. His special interests include physical-chemical relationships of soils, especially of soil colloids. Dr. Bradfield's interests in soil investigations have been centered around soil colloids but with a great concern in the problems of practical agriculture.

Dr. Bradfield has served on various committees of the Society and has participated in the programs of many annual meetings. As a member of the Committee on Reorganization of the Society in 1931, and as chairman of the Joint Committee for Reorganization of Soil Science Societies in 1935, he has contributed much to the progress of the Society and of soil science in America.

CHARLES ERNEST MILLAR

Charles Ernest Millar, Michigan State College; Michigan Agricultural Experiment Station, East Lansing, Michigan. Born at Mattoon, Illinois, June 23, 1885. B.S., University of Illinois, 1909; Graduate Assistant, University of Illinois 1909–1910; Assistant Chemist, Kansas State Agricultural College, 1910–1911; M.S., Kansas State Agricultural College, 1911; Assistant in Soils, 1913–1915; B.S. in Agriculture, Kansas State Agricultural College, 1915; Assistant Professor of Soils, Michigan State College, 1915–1918; Associate Professor, 1918–1925; Ph.D., University of Wisconsin, 1923; Professor of Soils, Michigan State College, 1925; Head of Department of Soils, Michigan State College, 1930—.

Member of American Society of Agronomy and American Soil Survey Association. While his special interests have been in soil fertility and land utilization, he has much interest in all phases of agronomic work.

Dr. Millar has served on many special committees, and is now chairman of the Soils Section of the Society.

MINUTES OF THE TWENTY-EIGHTH ANNUAL MEETING OF THE SOCIETY

The twenty-eighth annual meeting of the Society was called to order by President H. K. Hayes of the University of Minnesota, at 9:00 a. m. on Thursday, December 5, 1935, at the Stevens Hotel, Chicago, Ill. There were 388 members registered during the meeting and considerably over 400 were in attendance at the various sessions.

The general program, which consisted of a symposium on "Regional Land Use", was given as follows:

1. In the Hard Red Spring Wheat Region. H. L. Walster, North Dakota State College.
2. In the Hard Red Winter Wheat Region. R. I. Throckmorton, Kansas State College.
3. In the Corn Belt. P. E. Brown, Iowa State College.

The annual dinner featuring the address of the president "Green Pastures for the Plant Breeder" (pages 957 to 962 of this number of the JOURNAL), was held on Thursday evening. The Crops and Soils Sections and Sub-sections presented programs on Thursday afternoon and on Friday and the Extension Section gave a program on Thursday afternoon. There were two sectional programs in Crops and three sectional programs in Soils on Friday. The International Crop Improvement Association meeting was held on Wednesday, December 4, with the Society, and the American Soil Survey Association met on Tuesday and Wednesday jointly with the Agronomy Society, and joined in the programs of the Soils Section and Sub-sections on Thursday and Friday. The Soybean Council met on Thursday at the noon hour and the Joint Committee on Fertilizer Applications with its two sub-committees met on Tuesday and Wednesday with arranged programs.

The President appointed the Auditing Committee, consisting of Dr. Richard Bradfield, *Chairman*, and Dr. H. K. Wilson. The Nominating Committee consisted of President Hayes, *Chairman*, Dr. A. L. Patrick and Dr. W. A. Albrecht from the Soils Section, and Prof. H. B. Sprague and Prof. A. M. Brunson from the Crops Section.

COMMITTEE REPORTS

VARIETAL STANDARDIZATION AND REGISTRATION

Dr. M. A. McCall, *Chairman*, presented the report of the Committee on Varietal Standardization and Registration, which, upon motion, was adopted as follows:

Since the last annual meeting, the Committee on Varietal Standardization and Registration has approved the registration of three wheat varieties, Clarkan, Comet, and Hymar, and of one oat variety, Support. The data on which registration is based are being submitted for publication elsewhere in the JOURNAL.

The Committee also reports progress on the registration of cotton varieties. A joint sub-committee of this Society and of the Agronomy Section of the Association of Southern Agricultural Workers, under the chairmanship of Dr. H. B. Brown of the Society Committee, after a careful survey and study, has prepared a list of 31 varieties which are recommended for adoption as standard varieties. These varieties were all in commercial production in 1930. They are as follows:

1. Acala–5
2. Acala–8
3. New Boykin
4. Cleveland–5
5. Cleveland–884
6. Piedmont Cleveland
7. Wannamaker Cleveland
8. Cook–307–6
9. Delfos
10. Delta and Pine Land–8
11. Delta and Pine Land–10
12. Deltatype Webber
13. Dixie-Triumph
14. Dixie–14
15. Express–121
16. Lightning Express
17. Half and Half
18. Kasch
19. Lone Star
20. Mebane
21. Missdel
22. Station Miller
23. Mexican Big Boll
24. Oklahoma Triumph–44
25. Pima
26. Rowden
27. Arkansas Rowden –40
28. Toole
29. Stoneville
30. Trice
31. Wilds

The preparation of adequate descriptions of these varieties involves many technical difficulties. Accordingly, a more or less preliminary description of each variety has been prepared, which is to be published elsewhere in the JOURNAL. A more complete study from which it is intended to develop a more adequate and complete description is being undertaken; but since this will require several years for completion, it is felt that the publication of preliminary descriptions is advisable. The descriptions as now prepared are in a form which it is believed will be useful in the preliminary stages of standardization and registration.

During the year a request was received for registering a variety of rye. Standards for the registration of this crop have not been adopted, and the matter is being submitted to the committee for consideration.

A U. S. Dept. of Agriculture technical bulletin on the classification of American sorghum varieties will shortly come from the press. Pending the appearance of this classification, your committee has delayed plans for registering sorghum varieties. It is expected that a plan will be submitted to the Society at its next annual meeting.

During the year there has been issued a revision of U. S. Dept. of Agriculture Bul. 1074, "Classification of American Wheat Varieties". This new classification, U. S. Dept. of Agriculture Tech. Bul. 459, "Classification of Wheat Varieties Grown in the United States", contains the descriptions of 77 new varieties not in the previous publication. Of these 77 varieties, 42 have been registered by the Society as improved varieties. The remaining 35 are not registered but are in commercial production. In registering as standard varieties the varieties named in the original list given in Department Bul. 1074, the Society recognized the principle that commercial production justified registration as a standard variety, but not as an improved variety. It would seem, therefore, that the 35 new varieties included in the new classification also should be registered as standard varieties. These new varieties and their suggested registration numbers are as follows:

Varieties	Registration Nos.	Varieties	Registration Nos.
Wilhelmina	279	Montana King	291
Escondido	280	Pusa 4	292
Oregon Zimmerman	281	Missouri Valley	293
Currawa	282	Red Indian	294
Redhart	283	V. P. I. 131	295
Renfrew	284	Marvel	296
Arco	285	Early Blackhull	297
Golden	286	Superhard	298
Powerclub	287	Cooperatorka	299
Hard Federation 31	288	Eagle Chief	300
Axminster	289	Nebraska No. 6	301
V. P. I. 112	290	Utah Kanred	302

Enid	303	Kruse	309
Redhull	304	Poso	310
Sea Island	305	Genro	311
Whiteman	306	Hood	312
Berkeley Rock	307	Barnatka	313
Hyper	308		

In summary, the following recommendations are presented to the Society for action:

1. The 31 cotton varieties listed above shall be recognized by the Society as standard varieties.
2. The 35 wheat varieties listed above shall be recognized as standard varieties.

H. B. Brown
J. A. Clark
E. F. Gaines
H. K. Hayes
W. J. Morse
J. H. Parker
T. R. Stanton
G. H. Stringfield
M. A. McCall, *Chairman*

EDUCATION IN AGRONOMY

Dr. R. J. Garber, *Chairman*, gave the report of the Committee on Education in Agronomy. Upon motion the report was accepted as follows:

The Committee on Education was fortunate in that it was assigned a specific task, namely, "to take up with the American Council on Education the matter of consideration and inclusion of the applied agricultural fields of work, in the studies of the Committee on Graduate Instruction of that council." By correspondence at infrequent intervals throughout the year your committee draw up suggestions regarding graduate work in agronomy and early in November transmitted them to Dean F. B. Mumford of the University of Missouri who was designated by the Executive Committee of the Association of Land Grant colleges and universities to act as liaison officer. The suggestions which are made a part of this report follow.

The Committee on Education of the American Society of Agronomy would like to call attention to the need for graduate instruction in the applied fields of agriculture, as well as in the underlying foundation sciences. While instruction in the latter is more fundamental and more necessary for satisfactory graduate training than is similar instruction in the applied fields of agriculture, it is nevertheless true that persons who expect to engage in agricultural research should be trained in agriculture as well as in the foundation subjects. The possibility of teaching fundamentals by using materials from the applied fields should not be overlooked. An institution which is equipped to offer adequate instruction both in the foundation and applied subjects is perhaps best fitted to offer graduate instruction for students in agriculture. On the other hand, it should be recognized that there are a number of institutions which excell in the quality of the graduate facilities offered, either in essential foundation sciences or in some highly specialized field of agriculture. Through cooperative arrangement, it should be possible for a student to pursue graduate studies in both these classes of institutions without unnecessary loss of time in attaining the desired degree. The value of graduate training in highly specialized fields of agriculture for students who expect to enter such highly specialized fields is apparent.

The Committee on Education in Agronomy believes that while the number of students pursuing graduate instruction in the several subdivisions of agronomy should not be arbitrarily limited for the present, it should nevertheless be the definite policy of responsible persons to encourage only the noticeably superior students to do graduate work. Stipends to worthy graduate assistants who possess superior ability are very worth while expenditures, but stipends to graduate students who are chosen primarily because they provide a cheap source of help in the laboratory or field routine are questionable. If agronomic research is to be maintained on a high plane, only high class students should be encouraged to engage in it.

The Committee on Education of the American Society of Agronomy is in sympathy with the purpose of attempting an evaluation of the various institutions offering graduate instruction such as was made by the Committee on Graduate Instruction of the American Council on Education, and covered in the report issued by that committee in April, 1934. It is believed, however, that the limitations of such surveys should be clearly recognized and the results presented only as a general guide for prospective graduate students. The two most dominating influences in the mind of a candidate in selecting an institution are the location of the major professor under whom the student wishes to study and, perhaps to a less extent, the amount of stipend, if any, he is to receive. The results of a survey such as the one mentioned above should serve to give the student supplementary information. The Committee believe that such supplementary information would be more useful to students of agriculture, and particularly in agronomy, if the relative strength of the various institutions in the subdivisions of the subject are revealed. As a guide to a workable classification in making such a survey, it is suggested that the subdivisions in agriculture in which major work is now offered for the doctorate in the various agricultural colleges be used. For agronomy this might include, in addition to the foundation subjects, the five subdivisions of soil fertility and chemistry, soil biology, soil morphology and classification, crop breeding, and crop production. There also exists a need for advanced training in crop morphology, crop ecology, and crop physiology. For the present, perhaps, this need may best be met by those institutions which offer satisfactory graduate training in crop production and in the necessary foundation subjects of plant physiology, ecology, and morphology. A suitable combination of fundamental and applied subjects for the advanced student of agronomy may also be provided through cooperation between two institutions.

It may be desirable in some instances to designate subdivisions of foundation subjects. For example, genetics certainly is fundamental to the study of plant breeding and the student in this field prefers to study plant genetics rather than animal genetics. It may be well, therefore, to obtain separate appraisals of these divisions of the foundation subjects. In a similar manner physiology may be divided into plant physiology and animal physiology.

Another feature of vital importance to a survey such as was conducted under the auspices of the American Council on Education is the personnel of the group who make up the appraisals on which the relative standing of institutions is based. With respect to agronomy it is suggested that at least 50% of the persons making up the group be actively engaged in research and not merely active in an administrative capacity. To the Committee it seems that a more just appraisal is likely to be obtained if the group charged with the responsibility of making the appraisals is composed about equally of younger men actively engaged in research in the particular subdivision under consideration and older and more experienced individuals who at present may be spending most of their research time directing others.

If surveys similar to the one mentioned above are to be useful, they must give up-to-date information. To do this a survey should be made at least once every five years, and when it is made, it should be done promptly and the report covering it published immediately.

Richard Bradfield   Leroy Powers
John H. Parker   R. J. Garber, *Chairman*

BIBLIOGRAPHY OF FIELD EXPERIMENTS

Dr. H. M. Steece, *Chairman*, presented the report of the Committee on Bibliography of Field Experiments. It was moved and carried that the report be accepted and printed in the Journal as follows:

The committee has compiled a bibliography of 134 titles of the more important contributions on the methodology of and interpretation of results of field plat experiments, either reported since or not included in the revised bibliography published in the Journal. (Vol. 25: 811–828. 1933.)

ADDITIONS TO BIBLIOGRAPHY ON STANDARDIZATION OF FIELD EXPERIMENTS

Barclay, C., and Grantham, J. Statistical methods in field experiments with rubber. Arch. Rubbercult. Nederland. Indië 17:219–234. 1933.

Bates, G. Notes on the layout and harvesting of experimental plots. Queensland Soc. Sugar Cane Tech. Proc. 3:89–91. 1932.

Beattie, J. H. The significance of plot size and shape in relation to field trials with carrots and onions. Cong. Internatl. Hort., 10th, Paris, Compt. Rend. 160–178. 1932.

Behrens, W. U. Ueber die berechnung des wirkungsgrades eines nährstoffes auf grund von feldversuchen. Zeitschr. Pflanzenernahr. Dung. u. Bodenk. B, Wirtsch.-Prakt. Teil 13:145–150. 1934.

Bigot, A. De toepassing van "Analysis of variance" bij proefvelden. Landbouwk. Tijdschr. Maandblad 46:640–652, 705–717. 1934.

Bogue, A. H. Estimating the yield of grain from the weather. U. S. Dept. Agr. Mo. Weather Rev. 62:334–337. 1934.

Bonazzi, A. Errors in field experimentation with ratoon cane. Proc. Ann. Confr. Assoc. Tecn. Azuc. Cuba 7:32–40. 1933.

Borden, R. J., and Kutsunai, Y. For better field experiments with fertilizers. Hawaii. Planters' Rec. 38:215–231. 1934.

Brady, J. A biological application of the analysis of co-variance. Jour. Roy. Stat. Soc. Suppl. 2:99–106. 1935.

Brewbaker, H. E. Studies of irrigation methods for sugar beets in northern Colorado. Jour. Amer. Soc. Agron. 26:222–231. 1934.

Brewbaker, H. E., and Deming, G. W. Effect of variations in stand on yield and quality of sugar beets grown under irrigation. Jour. Agr. Res. 50:195–120. 1935.

Brown, H. M. Tables for calculating the standard error and the probable error of the coefficient of variability. Jour. Amer. Soc. Agron. 26:65–69. 1934.

Cochran, W. G. A note on the influence of rainfall on the yield of cereals in relation to manurial treatment. Jour. Agr. Sci. 25:510–522. 1935.

Coombs, A. V. The border effect in plot experiments. Empire Jour. Expt. Agr. 2: 315–323. 1934.

Crowther, F., and Mahmoud, A. Experiments in Egypt on the interaction of factors in crop growth. 1. A preliminary investigation of the interrelation of variety, spacing, nitrogen and water supply, with reference to yields of cotton. Bul. Roy. Agr. Soc. Egypt Tech. Sect. 22:34. 1935.

Davies, J. G., and Trumble, H. C. Notes on the technique of pasture investigations. Imp. Bur. Plant Genetics: Herbage Plants, Bul. 14:23–32. 1934.

Davies, W. Pasture sampling, with particular reference to methods used in Great Britain for determining the botanical composition of grassland. Rep. 3rd Grassl. Conf. Zurich. 203–207. 1934.

Davis, F. L. A study of the deviation of yields from duplicate pot cultures. Jour. Amer. Soc. Agron. 26:831–838. 1934.

Deming, G. W., and Brewbaker, H. E. Border effect in sugar beets. Jour. Amer. Soc. Agron. 26:615–619. 1934.

Deming, W. E. The chi-test and curve fitting. Jour. Amer. Statis. Assoc. 29:372–382. 1934.

Denison, F. C. Differential field fertilization. Assoc. Hawaii. Sugar Techno. Rpt. 13:37–47. 1934.

Dennett, J. H. The layout of field experiments. Malayan Agr. Jour. 22:276–283. 1934.

Dillowijn, C. van, and Levert, L. Stickstofoptimum on randeffect bij suikerriet. Arch. Suikerindus. Nederland. Indië, deel I, 41:569–582. 1933.

Dirks, B. Feldversuch und bodenuntersuchung als grundlage für die düngerberatung. Kühn-Arch. 38:164–174. 1933.

Duley, F. L. Outlying experiment fields as a means of determining the fertility of different soil types. Jour. Amer. Soc. Agron. 26:25–29. 1934.

Duley, F. L., and Ackerman, F. G. Run-off and erosion from plots of different lengths. Jour. Agr. Res. 48:505–510. 1934.

Eden, T. The development of field experiments in agricultural research. Trop. Agr. (Ceylon) 84:63–91, 131–149, 188–195. 1935.

Evans, H. Some preliminary data concerning the best shape and size of plot for field experiments with sugarcane. Mauritius Dept. Agr. Sugarcane Res. Sta. Bul. 3. 1934.

Fisher, R. A. Statistical methods for research workers. 5 ed. Oliver & Boyd. London. 1934.

Fisher, R. A., and Yates, F. The 6 X 6 Latin squares. Proc. Cam. Phil. Soc. 30: 492–507. 1934.

Frankena, H. J. Eon weeginstrument voor proefvelden. (A weighing apparatus for experiment fields.) Nieuwe Veldbode. 47:4. 1934.

Frankena, H. J. Bijdrage tot de kennis van de proefveldtechnick bij grasland. Dept. Landb., Nijv. en Handel [Netherlands], Verslag Dir. Landb. 40:22. 1934.

Garber, R. J., and McIlvaine, T. C. Analysis of variance of corn yields obtained in crop rotation experiments. Jour. Amer. Soc. Agron. 27:480–485. 1935.

Garner, F. H., Grantham, J., and Sanders, H. G. The value of covariance in analyzing field experimental data. Jour. Agr. Sci. 24:250–259. 1934.

Gracie, D. S., and Khalil, F. An analysis of the factors governing the response to manuring of cotton in Egypt. Bul. Tech. & Sci. Serv. Min. Agr. Egypt 152:71. 1935.

Greaney, F. J. Method of estimating losses from cereal rusts. Proc. World's Grain Exh. & Conf. Regina, Canada. 2:224–236. 1935.

Hanson, H. C. A comparison of methods of botanical analysis of the native prairie in western North Dakota. Jour. Agr. Res. 49:815–842. 1934.

Heath, O. V. S. A simple apparatus for measuring the compactness of soil in the field and some results obtained in a cultivation experiment. Empire Jour. Expt. Agr. 2:205–212. 1934.

Heath, O. V. S. Sampling and growth observations in plant development studies on cotton. Empire Cotton Growing Corp. Conf. Cotton Growing Problems, 2d, London, 1934, Rpt. 96–110. 1934.

Hendrickson, A. H., and Veihmeyer, F. J. The maintenance of predetermined soil-moisture conditions in irrigation experiments. Amer. Soc. Hort. Sci. Proc. (1933) 30:421–425. 1934.

Hollowell, E. A., and Heusinkveld, D. Border effect studies of red clover and alfalfa. Jour. Amer. Soc. Agron. 25:779–789. 1933.

Hopkins, J. W. Weather and wheat yield in western Canada. I. Influence of rainfall and temperature during the growing season on plot yields. Canad. Jour. Res. 12:306–334. 1934.

Hsu, T. S. Studies of some remedies for the missing plants in kaoliang experiments. Jour. Agr. Assoc. China 128:70–95. 1934. Eng. abs.

Huber, L. L., and Sleesman, J. P. Technique of field experimentation in entomology. I. Some principles involved in a well-planned experiment. II. The reduction of data by the method of analysis of variance. Jour. Econ. Ent. 27:1166–1170, 1934; 28:70–76, 1935.

Hudig, J. Modern grondonderzoek. Landbouwk. Tijdschr. Maandbl. 46:354–364. 1934.

Hudson, A. W., and Bates, E. M. Potato-manuring experiments. Investigations into the effect of width of plots on yield determination. New Zeal. Jour. Agr. 48:90–96. 1934.

Hudson, A. W., and Stafford, W. C. The rate of seeding of wheat in relation to variety trials. Emp. Jour. Expt. Agr. 2:29–39. 1934.

Hutchinson, J. B., and Panse, V. G. Studies in the technique of field experiments. I. Size, shape and arrangement of plots in cotton trials. Indian Jour. Agr. Sci. 5:523–538. 1935.

Immer, F. R. Varietal competition as a factor in yield trials with sugar beets. Jour. Amer. Soc. Agron. 26:251–261. 1934.

Immer, F. R., and Ausemus, E. R. A statistical study of wheat and oat strains grown, in rod row trials. Jour. Amer. Soc. Agron. 23:118–131. 1931.

Immer, F. R., Hayes, H. K., and Powers, L. Statistical determination of barley varietal adaptation. Jour. Amer. Soc. Agron. 26:403–419. 1934.

Immer, F. R., and Raleigh, S. M. Further studies of size and shape of plot in relation to field experiments with sugar beets. Jour. Agr. Res. 47:591–598. 1933.

Immer, F. R., and Stevenson, F. J. A biometrical study of factors affecting yield in oats. Jour. Amer. Soc. Agron. 20:1108–1119. 1928.

Jenkins, M. T. Methods of estimating the performance of double crosses in corn. Jour. Amer. Soc. Agron. 26:199–204. 1934.

Kalamkar, R. J. The influence of rainfall on the yield of mangolds at Rothamsted. Jour. Agr. Sci. 23:571–579. 1933.

Kalamkar, R. J., and Singh, S. A statistical examination of the yield of wheat at the Cawnpore Agricultural College Farm, Part I. Indian Jour. Agr. Sci. 5:346–354. 1935.

Kemp, H. J. Mechanical aids to crop experiments. Sci. Agr. 15:488–506. 1935.

Kerr, H. W. Some theoretical aspects of plot experimentation. Queensland Soc. Sugar Cane Technol. Proc. (1932) 3:77–87. 1934.

Kiesselbach, T. A., and Weihing, R. M. Effect of stand irregularities upon the acre yield and plant variability of corn. Jour. Agr. Res. 47:399–416. 1933.

Klapp, E. Methods of studying grassland stands. Herb. Rev. Imp. Bur. Gen. 3:1–8. 1935. (Transl. by G. M. Roseveare.)

Knight, R. L. The effect of shade on American cotton. Emp. Jour. Expt. Agr. 3:31–40. 1935.

Knott, J. C., Hodgson, R. E., and Ellington, E. V. Methods of measuring pasture yields with dairy cattle. Washington Agr. Expt. Sta. Bul. 295:20. 1934.

Lambert, A. R., and Crowther, F. Further experiments on the interrelation of factors controlling the production of cotton under irrigation in the Sudan. Pt. I. Experimental. Emp. Jour. Expt. Agr. 3:276–288. 1935.

Levensson, E. Vergleich zwischen feldversuchen und laboratoriumsuntersuchungen zur bestimmung der düngungsbedürfnisses des bodens. Bul. Soc. Bot. Bulgarie 6:86–113. 1934. Bulgarian with Ger. abs.

Livermore, J. R. The interrelations of various probability tables and a modification of Student's probability table for the argument "t". Jour. Amer. Soc. Agron. 26:665–673. 1934.

Livermore, J. R. The potato field trial. Amer. Potato Jour. 12:142–150. 1935.

Lobashev (Lobashow), P. G. The method of the field experiment and its application in conditions of large socialist farms. (Trudy Vsesoiuzn. Nauch. Issledov. Inst. Zerno-Bobovykh Kult. [Moskva] (Bul. Res. Inst. Legum. Grain Crops), I. 1935. Eng. abs.

Love, H. H. A table for transforming the correlation coefficient, r, to z for correlation analysis. Jour. Amer. Soc. Agron. 27:807–812. 1935.

McClelland, C. K. Border rows of oat plats as affecting yields and variability. Jour. Amer. Soc. Agron. 26:491–496. 1934.

Mack, W. B. Methods in variety trials. Amer. Soc. Hort. Sci Proc. (1934) 32:491–492. 1935.

Mader, W., and Dotzler, F. Eine maiszuchtmethode in experimenteller prüfung. Züchter 6:12–19. 1934.

Magistad, O. C., and Farden, C. A. Experimental error in field experiments with pineapples. Jour. Amer. Soc. Agron. 26:631–644. 1934.

Metzger, W. H. The relation of varying rainfall to soil heterogeneity as measured by crop production. Jour. Amer. Soc. Agron. 27:274–278. 1935.

Michels, C. A., and Schwenderman, J. Determining yields on experimental plats by the square yard method. Jour. Amer. Soc. Agron. 26:993–1001. 1934.

Miles, S. R. A new table of odds based on Student's table of probability. Jour. Amer. Soc. Agron. 26:341–346. 1934.

Miles, S. R. A very rapid and easy method of testing the reliability of an average and a discussion of the normal and binomial methods. Jour. Amer. Soc. Agron. 27:21–31. 1935.

Mooers, C. A. The influence of soil productivity on the order of yield in a varietal trial of corn. Jour. Amer. Soc. Agron. 25:796–800. 1933.

Muramatsu, S. The study of field estimation of missing plot in field experiments with Italian millet. I. The influence of missing plot on the growth and yield of adjacent plants. II. Relation between the yield estimation and yield increase of missing plot. Sapporo Soc. Agr. and For. Jour. 25:395–404; 26:228–240. 1934. In Japanese.

Murray, R. K. S. The value of a uniformity trial in field experimentation with rubber. Jour. Agr. Sci. 24:177–184. 1934.

Murray, S. M., and Glover, P. Some practical points regarding the detailed botanical analysis of grass-veld or other pastures by the list quadrat method. Jour. Ecol. 23:536–539. 1935.

Neubauer, H. Die stellung der bodenuntersuchung zum feldversuch und der keimpflanzenmethoden zü den ubrigen methoden der bodenuntersuchung. Soil Res. 4:234–250. 1935. French abs.

Neyman, J. Mathematical theorems involved in the solution of a broad class of agricultural problems. Rocz. Nauk Rolnicz. 31:223–276. 1934. In Polish. Eng. abs.

Neyman, J., Iwaszkiewicz, K., and Kolodziejczyk, S. Statistical problems in agricultural experimentation. Jour. Roy. Stat. Soc. Vol. 2, Suppl. 2:107–154. 1935.

Niklas, H., and Miller, M. Die ausschaltung der ungleichheit des bodens bei feldversuchen nach dem trendverfahren. Landw. Jahrb. 80:453–457. 1934.

Niklas, H., and Miller, M. The use of the weighted mean in agricultural experimental work with special reference to biological methods of soil investigation. Ernähr. Pflanze 30:47–48. 1934. (trans. title) In German. Eng. abs.

Niklas, H., and Miller, M. How can lack of uniformity in soils be ascertained and mathematically adjusted in agricultural field trials? (trans. title) Z. Pflanz. Düng., 35:328–334. 1935.

Opitz, K., and Rathsack, K. Der versuch einer nährstoffkontrolle von börde und sandboden, durchgeführt auf grund von statischen felddüngungsversuchen mit hilfe der methoden Mitscherlich und Neubauer. Landw. Jahrb. 81:129–175. 1935.

Ostermayer, A. Statistische studien über die beziehungen von bodenbearbeitung und ernten. Pflanzenbau 11:161–172. 1934.

Pan, C. L. Uniformity trials with rice. Jour. Amer. Soc. Agron. 27:279–285. 1935.

Papadakis, J. S. The pocket method of varieties experiments. Inst. Kallit. Fyton Thessalonike Epist. Delt. (Inst. Plant Breeding, Salonica, Greece, Sci. Bul.) 21:8. 1935. Eng. abs.

Paterson, D. D. A note on the value of correlation and regression in statistical analysis. Trop. Agr. [Trinidad] 11:160–169, 220–229. 1934.

Paterson, D. D. Experimentation and applied statistics for the practical agriculturist. (concl.) Trop. Agr. [Trinidad] 10:346–351. 1933.

Peh, S. C. A modern method of field experiment on rice. Lingnan Agr. Jour. 1:15–27. 1934. In Chinese.

Pope, O. A. Effects of certain soil types, seasonal conditions, and fertilizer treatments on length and strength of cotton fiber. Arkansas Agr. Expt. Sta. Bul. 319:98. 1935.

Przyborowski, J., and Wilenski, H. Wyzyskanie korelacji miedzy plonem i innemi mierzalnemi cechami poletek przy opracowywaniu doswiadczen polowych. (On the use of correlation between yield and other measurable characters of single plots in reducing results of field experiments.) Roczn. Nauk Rolnicz. i Lesn. (Polish Agr. and For. Ann.) 34:273–286. 1935. Eng. abs.

Quinby, J. R., and Stephens, J. C. The accuracy of cotton lint percentage figures. Jour. Amer. Soc. Agron. 22:157–163. 1930.

Quinby, J. R., and Stephens, J. C. Percentage of lint in distributed plats of cotton varieties. Jour. Amer. Soc. Agron. 23:67–69. 1931.

Rajabhooshanam, D. S. Application of modern statistical methods to yield trials. Agr. and Livestock, India. 5:145–155. 1935.

Reynolds, E. B., Killough, D. T., and Vantine, J. T. Size, shape, and replication of plats for field experiments with cotton. Jour. Amer. Soc. Agron. 26:725–734. 1934.

Robertson, D. W., Kezer, A., Sjogren, J., and Koonce, D. Studies on the critical period for applying irrigation water to wheat. Colorado Agr. Expt. Sta. Tech. Bul. 11. 1934.

Robertson, D. W., and Koonce, D. Border effect in irrigated plots of Marquis wheat receiving water at different times. Jour. Agr. Res. 48:157–166. 1934.

Scheffer, F. Bestimmung des nährstoffvorrates im feldversuch und im gefässversuch nach Mitscherlich. Kühn-Arch. 38:141–163. 1933.

Shen, L. Statistical analysis of a blank test of rice with suggestions for field technique. Agr. Sinica 1:107–150. 1934. In Eng. and Chinese.

Shiao, F. A study on the field technique of cotton. Jour. Agr. Assoc. China 114:53–90. 1933. In Chinese.

Skuderna, A. W., et al. Agronomic evaluation tests on mechanical blocking and cross cultivation of sugar beets. U. S. Dept. Agr. Circ. 316. 1934.

Smith, H. F., and Myers, C. H. A biometrical analysis of yield trials with timothy varieties using rod rows. Jour. Amer. Soc. Agron. 26:117–128. 1934.

Sokolow, A. W. Zur methodik der bodenuntersuchungen bei feldund gefässversuchen. Zeitschr. Pflanzenernähr. Düng. u. Bodenk. A, Wiss. Teil. 34:129–139. 1934.

Soltikovsky, M. J. I. The methods of analyzing and testing the winter crops cold resistance in the field. II. The summer death and sterility of winter crops. III. The winter crops death under ice crust. Trudy Selekts. Saratov Selekts.-Genet. Stan. (Proc. Gen. Sta. Plant-breed. and Gen. Saratov) 1:1–81. 1934. Russian with Eng. abs.

Strickland, A. G. Error in horticultural experiments. Jour. Dept. Agr. Victoria 33:408–416. 1935.

Stroman, G. N. Procedure for rapid calculation of multiple correlation coefficients. Jour. Agr. Res. 50 (1):59–69. 1935.

Summerby, R. The value of preliminary uniformity trials in increasing the precision of field experiments. Macdonald Coll. Tech. Bul. 15:64. 1934.

Suneson, C. A., and Kiesselbach, T. A. Differential varietal responses of winter wheat to time of planting. Jour. Amer. Soc. Agron. 26:294–296. 1934.

Tinley, N. L. The field work of agricultural crop trials. Jour. S. E. Agr. Coll. 36:122–128. 1935.

Tysdal, H. M. An analysis of soil and seasonal effects in alfalfa variety tests. Jour. Amer. Soc. Agron. 27:384–391. 1935.

Vaidyanathan, M. The method of 'covariance' applicable to the utilization of the previous crop records for judging the improved precision of experiments. Indian Jour. Agr. Sci. 4:327–342. 1934.

Vries, O. de. The reciprocal relationships between different aspects of fertilizer research as a polydimensional problem. Ernähr. Pflanze 30:373–381, 391–392. 1934. In Ger. Eng. abs.

Wang, C. M. Richey's moving average method as compared with Fisher's variance method. Jour. Agr. Assoc. China. 132:1–27. 1935. In Chinese.

Wang, H. T. Discussion of cotton experiment methods. Jour. Agr. Assoc. China. 116:47–56. 1933. In Chinese.

Wang, S. Effect of the length of row, number of replications and frequency of checks on the accuracy of soybean experiments under the environmental conditions of Nanking, China. Jour. Agr. Assoc. China. 132:49–62. 1935. In Chinese. Eng. abs.

Weatherspoon, J. H., and Wentz, J. B. A statistical analysis of yield factors in soybeans. Jour. Amer. Soc. Agron. 26:524–531. 1934.

Weidemann, A. G. A portable small grain thresher. Jour. Amer. Soc. Agron. 26:346–352. 1934.

Wiebe, G. A. Variation and correlation in grain yield among 1,500 wheat nursery plots. Jour. Agr. Res. 50:331–357. 1935.

Willard, D. R., and Smith, J. B. Variability in measurements of height and width of market garden plants. Jour. Amer. Soc. Agron. 27:798–799. 1935.

Wishart, J. Analysis of variance and analysis of co-variance, their meaning, and their application in crop experimentation. Emp. Cotton Growing Corp. Conf. Cotton Growing Problems, 2d, London. 1934 Rpt. 83–96. 1934.

Wishart, J. Field experimentation—the modern technique. Agr. Prog. 11:149–156. 1934.

Wishart, J., and Sanders, H. G. Principles and practice of field experimentation. London, Emp. Cotton Growing Corp. 1935.

Yang, Y. K. Suggestion of a new formula for the deviation of the mean method. Hopei Agr. Sci. 1:29–48. 1935. In Chinese. Eng. abs.

Yang, Y. K., and Tsuei, C. Y. A study of the application of some methods for calculating experimental errors. Hopei Agr. Sci. 1:49–72. 1935. In Chinese. Eng. abs.

Yates, F. Complex experiments. Jour. Roy. Stat. Soc. Vol. 2, Suppl. 2:181–223. 1935.

Yates, F. The formation of Latin squares for use in field experiments. Emp. Jour. Expt. Agr. 1:235–244. 1933.

Yates, F., and Watson, D. J. Observer's bias in sampling observations on wheat. Emp. Jour. Expt. Agr. 2:174–177. 1934.

Yates, F., and Zacopanay, I. The estimation of the efficiency of sampling, with special reference to sampling for yield in cereal experiments. Jour. Agr. Sci. 25:545–577. 1935.

Zinzadze, C. Bibliography of statistical methods, chiefly on the application of the analysis of variance. Imp. Bur. Soil Sci. Mo. Letter 40. 1935.

The observation, measurement and recording of crop loss and crop yield. Emp. Cotton Growing Corp., Conf. Cotton Growing Problems, 2d, London, 1934, Rpt. 78–83. 1934.

F. R. Immer J. T. McClure
T. A. Kiesselbach H. M. Steece, *Chairman*

PASTURE RESEARCH

Prof. A. E. Aldous gave the report of the Committee on Pasture Research, which upon motion was accepted as follows:

Strenuous attempts were made during the past year to combine the report on pasture investigations technic presented by this Committee November 22, 1934, with similar reports from committees of the Dairy Science Association and the American Society of Animal Production. These efforts have been unavailing, probably because of the inability of representatives of the three committees to meet at any time for conference. In the absence of this much-desired joint report, your committee wishes to present for consideration and publication, if approved, a report on the technic of grazing investigations in the arid and semiarid regions. This report was prepared by Dr. George Stewart with the assistance of W. R. Chapline and Wm. A. Dayton, all of the Division of Range Research, Forest Service, U. S. Dept. of Agriculture, and provides a needed supplement to the report of 1934 which considered only pasture experiments in the humid and irrigated sections of the United States. (N. B. This report will appear in an early number of the Journal.)

If the committee is continued, it is intended to take up next the presentation of a pasture research program for the future, or more specifically, a statement of pasture problems which need investigation and in connection therewith recommendations for coordinating pasture research in various sections of the United States. It is believed that certain state experiment stations and research divisions of the U. S. Dept. of Agriculture are especially well qualified, because of existing trained personnel and equipment, to solve some particular type of problem. A suitable assignment of each important problem might thus be effectuated so as to complete the entire program. There is little doubt that each agency would voluntarily accept responsibility for some definite problem which was obviously important in their section, if a reasonable distribution of the attendant work and expense could be devised so that such duties would not interfere with their immediate and more local activities. The Bankhead-Jones funds provide at this time an especially favorable opportunity to engage in such a comprehensive attack on the task of developing our long-neglected pasture resources to a point where they would make much more nearly their potential contribution to a successful agricultural program.

L. F. GRABER
A. E. ALDOUS
B. A. BROWN
GEORGE STEWART
PAUL TABOR
H. N. VINALL, *Chairman*

FERTILIZERS

Prof. R. M. Salter, *Chairman*, presented the report of the Committee on Fertilizers which, upon motion, was adopted as follows:

The Committee on Fertilizers comprises three sub-committees dealing respectively with fertilizer application, fertilizer reaction, and soil testing. The work of the committee has been directed along these three lines which later will be given separate consideration in this report.

The entire Committee held a two-day joint meeting with the National Joint Committee on Fertilizer Application in Chicago on December 3 and 4. At this meeting separate sessions were devoted to reports and papers covering the work on fertilizer application, fertilizer reaction, and soil testing. These were open meetings and the large attendance, 60 on December 3 and 123 on December 4, indicates a wide interest in the work of the Committee.

At a meeting of the Committee as a whole on December 3, the need for enlarging the scope of the Committee's activities was discussed, and it was voted that the Executive Committee of the Society be asked to give consideration to the appointment of two additional sub-committees, one to study the symptoms of mal-nutrition in plants and to prepare reproductions in color, together with accurate descriptions of such symptoms, with the thought that a book or monograph may be published when the material has been assembled. Another sub-committee is suggested to study plant-food ratios with the idea of making recommendations that will be helpful in the selection of fertilizer grades.

The Sub-committee on Fertilizer Application has functioned as one of the constituent sub-committees of the National Joint Committee on Fertilizer Application. During the year, under the sponsorship of the Joint Committee, studies of machine application of fertilizers have been conducted at 44 locations in 15 states, involving the following crops: snap, lima, and white beans, cabbage, corn, cotton, kale, peas, potatoes, spinach, sugar beets, tobacco, and tomatoes. Detailed reports of these studies will be published in the *Proceedings* of the Eleventh Annual Meeting of the National Joint Committee on Fertilizer Application which may be obtained from H. R. Smalley, Secretary of the Joint Committee.

At the meeting of the Joint Committee on December 4, a sub-committee was appointed and plans were considered for the dissemination of the results of the fertilizer application studies to farmers.

The Sub-committee on Fertilizer Reaction held a meeting in Pittsburg in December at which an agreement was reached upon the following objectives:

To study the controversial details of the method of chemical appraisal proposed by Pierre so that an analytical method might be proposed for approval by the Association of Official Agricultural Chemists.

To determine the efficiency of materials suitable for use as neutralizing agents in fertilizers with regard to the kind of material and the particle size.

The results of experimental work conducted according to plans formulated by members of the sub-committee were summarized and presented to the A. O. A. C. in November. The Association accepted the recommendations of the sub-committee and approved Pierre's method of analysis.

A program of six papers was arranged and presented at the general meeting on December 3.

The Sub-committee on Soil Testing held an informal meeting at Pittsburg in December, 1934, and set up the following five principal objectives for its work:

1. Collection and storage of a series of soil samples of known history and fertilizer response for use by investigators working on the development and improvement of methods and by service men for checking their testing technic.
2. Encouragement of the experiment stations in the study and comparison of the various rapid soil tests on their own fertility plats.
3. Presentation of a soil testing program at the 1935 meeting of the Society in Chicago.
4. A survey in the various states to determine what soil testing service is being offered, how this service is being handled, and what agronomists consider to be the proper agencies for this service.
5. A soil testing tour to provide an opportunity for study and comparison of the various rapid soil tests under different soil and climatic conditions and with different types of farming.

A full day's program, consisting of seven papers was presented at the committee meeting on December 4.

As a whole, it is believed that gratifying progress has been made toward the attainment of the objectives set up.

ROBT. M. SALTER, *Chairman*

STUDENT SECTIONS

Dr. H. K. Wilson gave the report of the Committee on Student Sections and announced the winners in the essay contest as follows:

During the past year, three additional chapters have joined the Student Section of the American Society of Agronomy. The institutions with chapters are:

Brigham Young University, Iowa State College, Kansas State College, Oklahoma A. & M. College, University of Illinois, University of Minnesota, University of Nebraska, Utah State College, Texas A. & M. College.

On December 1, the Student Section held its first meeting as a group. At this meeting 27 students representing five institutions were present. Officers were elected and plans were made for next year's work. The group expects to hold an annual meeting each year probably at the time of the Intercollegiate Crops Judging Contest.

Ten papers were entered this year in the essay contest sponsored by the American Society of Agronomy, indicating increased interest in this activity. The essays were judged by Professor A. L. Frolik, University of Nebraska, Professor J. W. Zahnley, Kansas State College, Professor G. H. Dungan, University of Illinois, and Professor T. E. Stoa, North Dakota State College. The winners of the three prizes were:

1. Kermit Greenley, University of Minnesota.
2. Horton M. Laude, Kansas State College.
3. Robert Jaccard, Kansas State College.

The committee recommends that the winning paper be published in the JOURNAL and that the Society sponsor the contest another year.

A. L. FROLIK
G. H. DUNGAN
E. R. HENSON
J. W. ZAHNLEY
H. K. WILSON,
Acting Chairman

The report of the committee was adopted and checks were presented to the winners in the essay contest for first and second prizes and an annual subscription to the JOURNAL for each of the three winners. The prize-winning essay follows.

METHODS IN CORN BREEDING

Kermit Greenley, *University of Minnesota*

Although intensive corn breeding programs are now carried on by most experiment stations, possibly the first conception of the value of corn breeding was held many years ago by the Indians, who planted seeds of different colors in the same hill with the belief that it increased yields. The corn crop has also played an important role in laying the foundation for an understanding of sexual reproduction in plants. As early as 1694, Camerarius demonstrated sex in plants thru the use of corn. Gartner in 1894 used corn extensively in his inclusive sex studies which involved nearly 700 species of plants.

In naturally self-pollinated crops, it is comparatively easy to isolate homozygous lines by selection which, if properly handled, should remain pure. With cross fertilized crops it is not so easy to control the male parentage and therefore the improvement of this type of crop is much more difficult. In either type of crop, however, the present day methods of improvement are based on the application of genetic principles and a knowledge of inheritance.

Early Methods of Corn Improvement

Among the more significant methods of early breeding may be included mass selection, ear to row selection and F_1 varietal crosses.

Mass selection.—Mass selection consists of picking out individuals with a definite type in mind and planting this seed in a bulk increase plot. Since corn is naturally cross-pollinated, mass selection under normal conditions considers only the female parent.

Selection may be made on the basis of ear type or plant type. The selection for ear type, which is synononously called the "Score Card Method", was extensively used about 1890 and is still in use among farmers.

Garrison and Richey (2)[1] have made a study of the effects of continuous selection for ear type. Their experiment involved six different strains of varying ear characters, i. e. smoothness, row number, ear length, and indentation. Continuous selection was practiced for 8 years. To quote from their report, the following statements are made:

"Without regard to reason, it is evident that close selection to any type, as practiced in their experiments, resulted in decreased productiveness.

"In their practical application the experiments indicate that a decrease in vigor and productiveness similar to that following inbreeding may result from too close a selection for a particular kind of ear."

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[1] Figures in parenthesis refer to "Literature Cited", p. 1024.

Hayes and Garber (4) point out that although Kiesselbach (8) obtained some benefit from the selection of long, slender, smooth seeded ears compared to rough or original seed, it is doubtful whether under any circumstances continued selection for any particular type of ear is desirable. Selection in the field from vigorous, healthy stalks appears to be a better procedure than ear selection and if long, slender, smooth ears are desirable field selection will lead to the production of this type.

Ear-to-row selection.—This type of corn improvement was first introduced by Hopkins of the Illinois Experiment Station in 1899. This method differs from mass selection in that a progeny test is made from each selected ear. Several modifications of the ear-to-row method have been devised. Williams' (14) method was to plant one-half the seed of each ear that was used for the ear-to-row test. The remnants of the ears whose progeny excelled in yielding ability were planted and the progeny intercrossed. Another feature of Williams' plan was to influence several breeders to work with the same variety so that new blood could be introduced into the ear-to-row plot every fourth or fifth year from a grower who was using the same breeding method. This was a cumbersome method, involving the use of a yearly plot for the ear-to-row test, an isolated plot for the crossing of remnants, a multiplication or seed plot, and a general field. Montgomery (10) suggested a plan which eliminated some of these difficulties. His plan was to grow an ear-to-row plot only once in several years and in the intervening years use a bulk seed plot planted by the hill method, selecting only from the vigorous stalks in perfect stand hills.

Kiesselbach (8), from studies on the effect of ear-to-row breeding on the yield of Haynes Yellow Dent concluded that no method of selection gave striking increases in yield. Hayes and Alexander (3) carried on studies with Rustler White Dent but the differences obtained were insignificant.

Ear-to-row breeding may be an effective method of improving a variety which has not been systematically selected, but in general it cannot be recommended as a means of increasing the yield of well adapted varieties. Smith and Brunson (13) concluded that mass selection was a far more effective simple method of selecting corn for yield.

Varietal crosses.—As early as 1876 Beal of the Michigan Agricultural Experiment Station called attention to the larger yields frequently obtained in the first generation after crossing two varieties of corn, and suggested that such F_1 crosses or hybrids might be used to obtain increased corn yields. Renewed interest in this subject was aroused as a result of publications of East (1) and Shull (12) on the effects of inbreeding and cross-breeding.

Many experiments with F_1 crosses compared to their parents have been made. Hayes and Olson (5) studied F_1 crosses over a five year period and found that on the *average* F_1 crosses yielded about the same as the *average* of the parents.

Hayes and Alexander (3) state, "Except for special conditions, it appears that F_1 varietal crosses are of no material value as a means of increasing yielding ability, provided a broad method of breeding is used without too close selection to type."

From a general survey of the early methods used in corn improvement, it is evident that none of these methods gave sufficient increases in yield or improvement in desirable plant or ear characters to warrant their continued use. From the standpoint of corn adaptation to shorter growing seasons, mass selection on the basis of early maturity has been of outstanding value. In Minnesota and other states on the northern edge of the corn belt, early strains from varieties are now being successfully grown which would not have been obtained without concentrated mass selection for earliness.

Present-Day Methods of Corn Improvement

The present day method of corn breeding has been defined by Richey (11) as a systematic effort to improve the crops by controlling the parentage of the seed.

East and Shull (1) (12) developed the method of breeding by controlled pollination as a result of their studies on the effects of inbreeding maize. They first began their studies in 1905, and in 1909 concluded that inbreeding was not harmful in itself because only the development of the plant was affected.

Shull (12) classified corn breeding into two headings. 1. Finding the best pure lines, and 2, the practical use of the pure lines in the production of seed corn. The problem of the corn breeder, therefore, was to produce inbred lines and find the best hybrid combinations between them.

Jones (6) explained hybrid vigor as being due to the interaction of dominant favorable growth factors, part of which were supplied by each parent.

Hayes (4) in reviewing the corn breeding situation in 1926 stated, "It is apparent that present day problems are concerned chiefly with the reaction of selfed lines and F_1 crosses between them."

Effects of Inbreeding

The effects of inbreeding may be discussed under three sub-headings.

Reduction of vigor.—All experiments have shown that reduction in size occurs in all parts of the plant as well as a decrease in productiveness and growth.

The actual decrease in productiveness varies greatly among inbred lines—some become so greatly weakened that they cannot be propagated. At the Minnesota station inbred lines of Golden Bantam sweet corn tend to be relatively more vigorous than field corn lines after comparable years of inbreeding.

Isolation of biotypes.—Together with reduction of vigor, strains having certain individual characteristics are obtained. For example, among inbred lines are found those having differential resistance to smut and root rot, varying degrees of resistance to lodging and stalk breaking, variation in time of maturity, diverse types varying in plant growth, ear character, etc. These various strains form the fundamental basis for selection of the most desirable types for use in hybrids.

Appearance of abnormalities.—In the process of inbreeding, many recessive plant and ear abnormalities which are normally present but masked by the dominant allelomorph appear in their homozygous recessive condition. Thus upon continued inbreeding those plants which develop undesirable fixed characters such as albino or pale green seedling, partly formed or malformed ears, etc. may be discarded.

Use of Inbred Lines

Since it has been shown that inbred strains are reduced in vigor, it is necessary to find the proper combination of selfed lines to recover the vigor lost during the inbreeding process and to utilize the desirable characters obtained by selection.

Various types of crosses have been studied; each type is briefly discussed below.

Single crosses.—This type of cross involves only two inbred strains, and the first crop between them is used for the commercial crop.

The utilization of single crosses for the commercial crop is in general handicapped because of the small and irregular seeds obtained from the reduced, non-vigorous, inbred plants, also, as most inbred strains are low in productiveness, the cost of the seed is great as long as inbred strains are used to produce the seed for the commercial crop. Inbred lines, however, can be used to produce commercial single crosses when their vigor is comparatively high.

In sweet corn, where uniformity of maturity, ear type, etc. is very important the use of single crosses offers exceptional advantages, since the normal open pollinated varieties are very variable in these characters. Thus the use of single crosses in sweet corn is a very effective way of increasing yield, along with uniformity of ear type and maturity so highly desired by the commercial canner.

Double crosses.—The double cross plan first suggested by Jones (6) overcomes most of the difficulties of the single cross. In making this cross, four selfed lines must be used. If these lines are designated as a, b, c and d, then a is crossed with b, and c with d. The two single crosses are then planted side by side in an isolated plot and one cross is detasseled to produce the double crossed seed on the detasseled parent. Since only vigorous F_1 crosses are used it follows that the seed will be of better quality and in greater quantity than when inbred lines are used. By this plan it is necessary to make three crosses; two crosses to obtain the two single crossed parents and the final double cross. Kiesselbach (9) has shown that advanced generation single crosses may be used instead of first generation single crosses as parents for the double cross. The use of an advanced generation single cross as a female parent is, however, not advisable since the yield of double crossed seed will be considerably reduced. Advanced generation single crosses are being used successfully at Minnesota as pollen parents with first generation female parents. This plan reduces the number of crossing plots to two since the advanced generation pollen parent is increased by sib pollination in the final crossing plot.

Three-way cross.—The procedure in this type of cross is to use a single cross as a female parent with a vigorous inbred line as pollen parent. Obviously it reduces the number of crosses to two; one for making the single cross and the other for the final hybrid. This method has the further advantage that only 3 inbred lines need be carried.

The results obtained from the present day methods of corn breeding have shown conclusively that increased productiveness and improvement in other desirable agronomic characters are far in excess of those obtained by the older methods of corn breeding. The method offers exceptional opportunity for the production of hybrids of specific characteristics by the proper selection of the inbred parents.

Since hybrid seed must be produced for each commercial crop grown, this plan opens new fields for the commercial production of hybrid seed corn. Many seed companies and farmer seedsmen are now engaged in this type of work.

Modern corn breeding methods are an excellent example of the possibilities for the application of sound genetic principles in the improvement of one of the most important farm crops in the United States.

Literature Cited

1. East, E. M. Inbreeding in corn. Conn. Agr. Exp. Sta. Rpt. 1907:419–428. 1908.
2. Garrison, H. S., and Richey, F. D. Effects of continuous selection for ear type in corn. U.S.D.A. Bul. 1341. 1925.
3. Hayes, H. K., and Alexander, Lee. Methods of corn breeding. Minn. Agr. Exp. Sta. Bul. 210. 1924.
4. ————, and Garber, R. Breeding Crop Plants. McGraw-Hill Book Co. Inc. 1927.
5. ————, and Olson, P. J. First generation crosses between standard Minnesota corn varieties. Minn. Agr. Exp. Sta. Bul. 183. 1919.
6. Jones, D. F. Linkage in Lycopersicum. Amer. Nat., 51:608–621. 1917.
7. Kiesselbach, T. A. Recent developments in our knowledge concerning corn. Neb. Corn Impr., Assoc. Rpt. 7:15–42. 1916.

8. ————. Corn investigations. Neb. Agr. Exp. Sta. Res. Bul. 20. 1922.
9. ————. The use of advanced generation hybrids as parents of double cross seed corn. Jour. Amer. Soc. Agron., 22:614–626. 1930.
10. MONTGOMERY, E. G. Experiments with corn. Neb. Agr. Exp. Sta. Bul. 112. 1909.
11. RICHEY, F. D. Corn breeding. U.S.D.A. Bul. 1489. 1927.
12. SCHULL, G. H. A pure line method of corn breeding. Amer. Breeders' Assoc. Rpt., 5:15–59. 1909.
13. SMITH, L. H., and BRUNSON, A. M. An experiment in selecting corn for yield by the method of the ear-row breeding plot. Ill. Agr. Exp. Sta. Bul. 271. 1925.
14. WILLIAMS, C. G. Pedigreed seed corn. Ohio Agr. Exp. Sta. Circ. 42. 1905.
15. ————. Corn breeding and registration. Ohio Agr. Exp. Sta. Circ. 66. 1907.

CHILEAN NITRATE RARER ELEMENT RESEARCH AWARD

Prof. R. I. Throckmorton, *Chairman*, presented the following report for the Committee on the Chilean Nitrate Rarer Element Research Award:

The Society accepted the responsibility of sponsoring a $5,000 award for research on the rarer elements in agriculture at the annual meeting in 1934. The award is made by Chilean Nitrate of Soda Educational Bureau. Eleven candidates were considered by the Committee. Three candidates were unanimously selected to receive the award.

The Committee wishes to remind the recipients that one of the rules under which the awards are made states that they are to be used in furthering research on the rarer elements or for professional advancement.

The recipients of the award are Dr. J. S. McHargue, University of Kentucky, Lexington, Ky; Dr. Anna L. Sommer, Agricultural Experiment Station, Auburn Ala.; and Dr. L. G. Willis, University of North Carolina, Raleigh, N. C.

Dr. J. S. McHargue, Head, Department of Chemistry, Kentucky Agricultural Experiment Station, Lexington, Ky., is recognized because of his excellent and extensive research on the occurrence of rarer elements in soils and plants. He has shown tremendous insight and initiative in pursuing research studies on the rarer elements. His work has undoubtedly been inspiring to other investigators.

Dr. Anna L. Sommer, Associate Soil Chemist, Agricultural Experiment Station, Auburn, Ala., is recognized because of the quantity and quality of her research work with the rarer elements, and because she has explored new fields in this line of study. Her work has been an inspiration to other workers and the research methods which she has devised have been helpful to others.

Dr. L. G. Willis, Soil Chemist, North Carolina Agricultural Experiment Station, Raleigh, N. C., is recognized because of the very extensive information on the rarer elements which he has given to agricultural science, and particularly for the work which he has done on soils and the relation of the rarer elements to plant growth.

H. H. ZIMMERLEY
A. T. WIANCKO
C. F. SHAW
J. G. LIPMAN
OSWALD SCHREINER
R. I. THROCKMORTON
Chairman

RESOLUTIONS

Prof. F. D. Keim, *Chairman*, presented the report of the Committee on Resolutions which was adopted as follows:

Following the procedure established with the appointment of a standing committee on Resolutions, your committee has continued, as one of its functions, to take note of the death of agronomists who have long been active in their lines of work. It is with sorrow and a feeling of great loss, therefore, that we must record the deaths since the last meeting of the Society of John S. Carroll, Jackson, Miss.; S. H. Essary, Agricultural Experiment Station, Knoxville, Tenn.; C. S. Marbut, Division of Soil Survey, U. S. Dept. of Agriculture, Washington, D. C.; G. B. Mortimer, College of Agriculture, Madison, Wisc.; and J. D. Tinsley, a charter member, Amarillo, Texas. A statement regarding the life and work of these men is made a part of this report.

JOHN S. CARROLL

In the sudden passing of John S. Carroll on September 15 at his home in Jackson, Mississippi, the fertilizer industry loses one of its oldest and best-known members. For more than thirty years, this Southern gentleman of the "old school" had been associated with the potash interests in agricultural and scientific work, and his friends, not only among scientific agriculturists but among the trade, were legion.

John Sharkey Carroll was born in Oktibbeha county, Mississippi, in 1871 and reared on a farm. He studied agriculture at the Mississippi Agricultural College, graduating in 1892 with the degree of Bachelor of Science.

He taught in the public schools of that state for two years and was then appointed instructor at the Mississippi Agricultural College, where he pursued graduate work in agricultural chemistry, receiving in 1896 the degree of Master of Science. One year was spent in graduate work in Chemistry at the University of Chicago.

In 1896 he was appointed to the position of Assistant Professor of Chemistry in the Mississippi Agricultural College and Assistant State Chemist with work in connection with the inspection and analysis of fertilizers. He continued in this work until 1904, when he accepted the position of manager of scientific and educational work of the German Kali Works for the southern states with offices in Atlanta, Georgia. Since then, with the exception of the late war period during which time he taught chemistry at the Mississippi Agricultural College, Mr. Carroll had been connected with the agricultural and scientific work of the potash interests, and at the time of his death was manager of the Southwest Territory for the American Potash Institute.

Mr. Carroll was a member of the American Association for the Advancement of Science, the Association of Southern Agricultural Workers, the American Society of Agronomy, American Chemical Society, and several other agricultural societies. He was also a member of several local organizations, including the Chamber of Commerce, University Club, and the Rotary Club. He is survived by Mrs. Carroll and daughter.—AMERICAN POTASH INSTITUTE, INC.

SAMUEL HENRY ESSARY

In the death of Samuel Henry Essary, the University of Tennessee has lost a capable and useful investigator. The summons came quickly and quietly at the home of a friend in Trenton, Sunday morning, April 28, 1935, following a busy day at the West Tennessee Experiment Station at Jackson. Such an end he doubtless would have chosen, had choice been possible.

A native of Henderson county, he graduated from the University of Tennessee in 1897. He took his Master's at this institution in 1907, and also spent some time in study at the University of Wisconsin. He taught at LaGrange College, Missouri, 1899–1901, and at Brenau College, Gainesville, Ga., 1902–1904; became associated, in 1904, with the late Professor Samuel M. Bain, head of the department of Botany of the University of Tennessee and the Experiment Station; was assistant in that department until 1919; and was then appointed to the position of Station Botanist, which he held until the time of his death.

Mr. Essary was recognized as one of the outstanding botanists of the South, a true naturalist and keen observer. He had a deep and abiding appreciation of the beautiful and good—in nature, music and literature—and a strong sense of loyalty that endeared him to all who knew him.

One of his first achievements in plant improvement work was the development, in cooperation with Professor Bain, of Tennessee Wilt-Resistant clover, which continues to be the best variety south of the Ohio River. Before its introduction the growing of red clover in Tennessee and other parts of the South had largely ceased because of the ravages of the anthracnose disease. Two wilt-resistant varieties of tomatoes—Tennessee Pink and Tennessee Red—selected by Mr. Essary, have been of inestimable value to growers in the trucking area of West Tennessee. Probably his most important contribution to agriculture is the Tennessee No. 76 lespedeza, developed from the common Japan clover, and now grown throughout the state as a hay and pasture crop.

For a number of years he had given special attention to the improvement of cotton by selection and breeding, having made over three hundred crosses with seven of the most promising varieties, in an effort to secure superior strains—high yielding and of high quality staple. Trice cotton, one of the best early varieties now grown along the northern border of the cotton-producing area, was improved and introduced to general use by him. In all his work he maintained a high scientific standard, while achieving results of great practical value. He will be long remembered by both botanists and farmers.

Mr. Essary was a Fellow of the American Association for the Advancement of Science; a member of the American Society of Agronomy, the American Genetics Association, the Tennessee Academy of Science, the American Phytopathological Society, and the Barnard Astronomical Society; a member of Phi Kappa Phi, Alpha Zeta, and S. A. E. Fraternities, and of the following Masonic orders: Masters Lodge No. 244, Pearl Chapter No. 24 R. A. M., Knoxville Council No. 75, Cour de Lion Commandery No. 9, and Kerbela Temple A. A. O. N. M. S., all of Knoxville. He was a member of Union Baptist Church of Chesterfield, Tennessee.

Mountain hiking was one of his hobbies, He was a pioneer in the blazing of trails in the Great Smokies, now a National Park. Pictures of peaks and studies of plant life made by him have been used in books that describe the Smoky Mountain area.

Mr. Essary was a gentleman. His unassuming, helpful, and sympathetic nature and his genial personality won for him many friends, who are deeply grieved at his going. He was a well loved figure at the University, and will be greatly missed, particularly by his associates in the Experiment Station and the College of Agriculture.

"A short life is given us by nature; but the memory of a well-spent life is eternal." His work stands as a monument to his life.—E. G. FRIZZELL.

CURTIS FLETCHER MARBUT

By the death of Curtis Fletcher Marbut, at Harbin, Manchukuo, on August 25, 1935, the American Society of Agronomy lost a loyal member and science one of its most distinguished authorities on the soils of the world.

Dr. Marbut was born on a farm in Lawrence County, Missouri, July 19, 1863. His early education was acquired in the short-term rural school of the community, and after securing a teacher's certificate he spent a brief time teaching in the rural schools during which period he prepared himself for college. A year after his graduation from the University of Missouri in 1889, he was appointed to the staff of the Missouri State Geological Survey and after spending a year in post-graduate work he received a master's degree from Harvard University in 1894. From 1894 to 1897 he was instructor in geology at the University of Missouri, assistant professor from 1897 to 1899, and professor from 1899 to 1910. In 1905 Dr. Marbut assumed directorship of the soil survey of the state and five years later left his native state to take active charge of the Federal Soil Survey project which had been inaugurated some years earlier by Dr. Milton Whitney. During the quarter of a century that followed, the area surveyed and mapped in detail and in reconnaissance increased from approximately 200 million acres to about one billion acres or substantially one-half of the land area of the United States. Under his direction the Soil Survey became one of the outstanding scientific undertakings of the Department of Agriculture. His scientific and scholarly approach to the subject gave great impetus not only to the soil work in this country but to soil research throughout the world. The detailed reports and maps of the areas that have been distributed during the progress of the survey has been supplemented by a single volume recently completed by Dr. Marbut. This volume, giving an inventory of the soil resources of the nation, which has just been published as Part III of the Atlas of American Agriculture will stand as a monument to his industry and perseverance in his chosen field of science.

Dr. Marbut's interest and knowledge of soils was not confined to his own country and even at the time of his death he was on his way to China for the purpose of assisting the Chinese Government in making an inventory of its vast soil resources. He had previously made personal examination of the soils of every country of Western Europe except those of Spain. He was also familiar with the great soil groups of Russia and had made trips into Africa and South America for the purpose of studying and classifying the soils of extensive regions on these continents. He consistently visualized the study of soils as an international problem and his wide experience had brought him recognition as one of the world's foremost authorities in the field of pedology. During the meetings of the First International Congress of Soil Science held in this country in 1927, he participated in practically all of the international undertakings for the promotion of soil classification including fundamental studies of soil genesis and morphology. At the Second International Congress held in Russia in 1930 and again at the Third Congress at Oxford, England in 1935, he rendered conspicuous service in defining the fundamental and universal processes of soil formation and assuring leadership in outlining the scope and purpose of soil science as a definite field of scientific endeavor.

In addition to those already mentioned, many honors came to Dr. Marbut including the LL.D. degree from his Alma Mater and the degree of D. Sc. from Rutgers University in 1930 conferred upon him at the celebration of the semi-centennial of the establishment of the New Jersey Agricultural Experiment Station. During the same year he received the Cullum Medal of the American

Geographical Society for his geographic work on the soil, "the foothold of all things". In addition to his membership in the American Geographic Society he was an honorary member of the Royal Geographic Society of Berlin and the Czechoslovakian Academy of Soil Science. He served as president of the Association of American Geographers in 1924 and was chairman of Section O of the American Association for the Advancement of Science in 1926. He was active in the organization of the American Soil Survey Association and in 1928 was made a fellow in the American Society of Agronomy.

Dr. Marbut had passed the age of retirement but had been retained for the third additional year in order to enable him to continue important researches on the morphology and classification of the soils of this and other countries and to prepare for publication the results of some of his recent studies.

In closing this brief sketch of the life of my dear good friend, I cannot do better than to quote from a letter written from Harbin the day following his death:

"To me he was a great and good teacher, which, according to Chinese traditions is next to being a father. He had such a great and contagious enthusiasm for his work that the men under him, and even those who sometimes disagreed with him, caught the contagion and were inspired to greater achievements. One of the greatest things about his nature was that, while he had strong convictions regarding the various phases of his investigations, he was always willing to change his views when convincing proofs were brought forward. He often asked to 'see the documents', but if the latter were convincing, he was ready to concede the point. It is truly amazing, however, that he was so seldom on the wrong track and nearly always considerably ahead of his colleagues. Glimpses of his wholesome and well balanced philosophy of life at various times and under different circumstances are a precious memory. A young or middle-aged man who has not had the friendship of an elderly man of Dr. Marbut's rare type is spared the grief which comes with his loss, but his life is also lacking in one of the greatest joys."—A. G. McCall.

GEORGE B. MORTIMER

G. B. Mortimer, Professor of Agronomy, Wisconsin College of Agriculture, passed over the Great Divide to receive the reward that is due him for his strenuous labor in behalf of agriculture throughout life. Professor Mortimer was known far and near throughout the University and the State of Wisconsin as a firm friend to the farmer and young people of the state. All classes of people miss him and think of his great worth while with us.

Brought up on a farm in the early days, he learned the habits of industry which continued with him throughout life. A thorough teacher, a great investigator, and one who has performed duties that will live for many years after his departure. Never was there a man in the history of our country that took a deeper interest in the work he had to perform than George B. Mortimer. His students were always welcome to come and see him and no matter how busy with technical affairs, he would always throw the work aside in order to give his students encouragement. He was considered one of the best teachers in the state University and his extension work was marked by exactness and practicability of presentation of subject. Professor Mortimer was one of the few individuals who could always speak to a farm audience in a language which all could understand. He avoided high technical terms as he felt that they meant very little, if anything, to the farmers. His work on pastures during the past six or eight years has given the world many new things to think about. It is too bad to lose men of this character when we need their services so badly. However, he has left us, but his work will go on for many years to come.—R. A. MOORE.

JOHN DABNEY TINSLEY

John Dabney Tinsley was born September 22, 1869, at Charlottesville, Va., and died in Amarillo, Texas, on August 5, 1935.

He attended the Miller School for boys in Albemarle County, Va., and after graduation from the University of Virginia returned to teach in that school for five years. In 1896 he joined the faculty of the New Mexico A. & M. College as professor of biology and two years later was put in charge of the irrigation investigations of the experiment station. In 1899 he organized a department of soil physics in the college and station and continued as head of the department until 1910, when he was named agricultural demonstrator for the Atchison, Topeka, and Santa Fe lines in New Mexico, with headquarters at Albuquerque. In 1913 he was transferred to Galveston, Texas, as agricultural agent for the Gulf, Colorado, and Santa Fe Railway Company. In 1923 he moved to Amarillo, Texas, to become General Agricultural Agent for the Panhandle and Sante Fe Railway Company and continued in this capacity until the time of his death.

Mr. Tinsley was a charter member of the American Society of Agronomy, a fact to which he often referred with pride, and he maintained his membership in the Society to the time of his death. He was first and last a scientist and won and held the esteem of his associates by his tolerant and patient attitude toward all with whom he came in contact.—N. H. MOHLER.

The Resolutions Committee, acting upon a request from the American Soil Survey Association, also recommends that the American Society of Agronomy approve the suggestion embodied in the report of the Committee on Soil Conservation of the American Soil Survey Association that a soil survey of unsurveyed agricultural lands be completed as rapidly as possible and on a national scale as being of fundamental importance in national and state land planning programs.

G. E. RITCHEY
E. F. GAINES
S. B. HASKELL
J. D. LUCKETT, *ex officio*
F. D. KEIM, *Chairman*

OFFICERS' REPORTS

REPORT OF THE EDITOR

Prof. J. D. Luckett, Editor, presented his report which upon motion, was accepted as follows:

It is our pleasure to submit herewith probably the most favorable report on the state of the JOURNAL that it has been our privilege to prepare for many years. This feeling of satisfaction is not due so much to the fact that the 1935 volume is particularly outstanding in size or quality; for in these respects it is probably just a good average volume of the JOURNAL. The satisfaction is found rather in the fact that the somewhat rigid restrictions that were set up two years ago to meet an acute emergency in the affairs of the JOURNAL have apparently served their purpose and might well be removed, at least in large measure, in 1936.

To make this report as brief as possible, we would state simply that in the 1935 volume we shall have 123 contributed articles, 12 notes, and 14 book reviews—a slight falling off from 1934 in number of contributed papers, but the two volumes will compare almost page for page in size. There are on hand at this time just sufficient papers to complete the January number of the JOURNAL, hence we are prepared to offer as prompt publication in 1936 as one may reasonably expect from a monthly journal.

Coupled with this favorable publication schedule is a fairly satisfactory financial situation, about which the Treasurer will give you more detailed information, all of which leads to the belief on the part of the Treasurer, the Editorial Advisory Committee, and myself that we may safely return to a more nearly normal basis of operation in the management of the JOURNAL next year.

Specific recommendations made to the Executive Committee, therefore, include the following points:

1. An increase in the number of pages of free publication allowed each contribution in the JOURNAL from the present limit of 8 pages to a new limit of 12 pages. In this connection you may be interested to know that of the 123 papers appearing in the 1935 volume, 89 contain 8 pages or less, while 111 contain 12 pages or less. Thus, increasing the limit of free pages to 12 will relieve a very large proportion of contributors of all restrictions on space. Also, these added pages should make possible a more comprehensive presentation of results without danger of incurring penalties for extra pages.
2. The establishment of a charge of $4.00 per page for each page beyond 12 pages to and including 16 pages; and a charge of $5.00 per page for each page beyond 16 pages.
3. An increase in the allowance for illustrations from $10 to $15 for each article.

With the opportunity for prompt publication and with most, if not all, financial restrictions removed, the JOURNAL should prove an attractive medium of publication in 1936.

The success of the JOURNAL this year, as in other years, is due in large measure to the generous cooperation of many persons who receive little or no recognition for their efforts beyond the personal satisfaction of rendering worth while service. These include the reviewers who labor over the papers submitted to the JOURNAL, the authors who accept our criticisms in such good spirit; the correspondents who supply us with timely news items; the advertisers who help pay our bills; the able and genial chairman of the Editorial Advisory Committee who guides our faltering steps; and most of all that dual-personality, the Secretary-Treasurer, who in his capacity as Secretary has the endless task of keeping our mailing lists in order, and as Treasurer must first collect and then disperse the funds that keep the JOURNAL coming to you on a regular schedule. To all of these we acknowledge a profound debt of gratitude.

In concluding this report, the thought that I would like to leave with you is that the JOURNAL has successfully weathered a really serious crisis in its affairs; that for the first time in several years we are in a position actually to encourage contributions to the JOURNAL; and that, in fact, we really should see more papers than we are seeing at the present time. We believe that this need can be quickly and easily met and are looking forward to your cooperation in this direction in the year ahead.

Submitted,
J. D. LUCKETT, *Editor*.

REPORT OF THE TREASURER

The Treasurer's report was presented, received, and referred to the Auditing Committee as follows:

I beg to submit herewith the report of the Treasurer for the year November 1, 1934, to November 25, 1935:

Receipts

Advertising income	$ 511.72	
Reprints sold	1,795.66	
JOURNALS sold	181.26	
Subscriptions, 1935	1,783.30	
Subscriptions, 1934	170.50	
Subscriptions, 1935, new	523.86	
Subscriptions, 1936	79.95	
Dues, 1935	3,524.82	
Dues, 1934	483.00	
Dues, 1935, new	700.50	
Dues, 1936	47.00	
Received on trust certificate	24.17	
Total receipts	$ 9,825.74	
Balance in cash, November 1, 1934	511.51	
Total income		$10,337.25

Disbursements

Printing the JOURNAL, etc	$ 8,003.69	
Salary Business Manager and Editor	802.68	
Postage (Secretary and Business Manager)	189.90	
Printing, miscellaneous	298.18	
Express on JOURNALS	31.48	
Mailing clerk	52.14	
Refunds, checks returned, etc	19.81	
Miscellaneous, annual meeting, etc	409.24	
Total disbursements		$ 9,807.12
Balance on hand, November 25, 1935		$ 530.13
Balance in trust certificate		296.99
Total balance in account		$ 827.12
Balance in cash on hand	$ 530.13	

Respectfully submitted,

P. E. BROWN, *Treasurer.*

REPORT OF THE ASSISTANT TREASURER

Dr. A. G. McCall, presented the report of the Assistant Treasurer, which was received and referred to the Auditing Committee as follows:

The status of the account of the American Society of Agronomy with the Executive Committee of the First International Congress of Soil Science as of November 16, 1934, to November 23, 1935, is as follows:

Receipts

Sale of Proceedings, First International Congress of Soil Science (1927)	$ 123.00	
Interest on savings account, Prince George's Bank and Trust Company, Hyattsville, Md.	64.50	
Membership dues from American members of International Society of Soil Science	1,062.50	
Credit by bank for check of John T. Miller for dues included in deposit of April 4, 1935 ($100.30) returned by bank for better endorsement; endorsement was correct and check redeposited April 10, 1935	6.80	
Balance on hand, Prince George's Bank and Trust Company, Hyattsville, Md., Nov. 15, 1934:		
Savings account	2,315.20	
Checking account	117.39	
Total receipts		$ 3,689.39

Expenditures

Postage (stamps and envelopes for office correspondence, transmittal of deposits, membership records, Proceedings orders, etc.)	$ 35.08	
Rumford Press, Concord, N. H., for handling and shipping sets of Proceedings of First Congress	15.56	
Tax on checks issued (bank charge)	.10	
Exchange (deducted by bank on 2 Honolulu checks (dues))	.70	
Premium on bond for Dr. A. G. McCall, Ass't. Treasurer	5.00	
Rubber stamp for endorsement of checks	1.70	
Express charge on film of the First International Congress shipped to New York for transportation to England for Third International Congress meeting	.71	
Bank deducted for check of John T. Miller returned for better endorsement; endorsement was correct and check redeposited April 10, 1935	6.80	
Transmittal of dues collected from American members and sent to Dr. D. J. Hissink, General Secretary of the International Society of Soil Science	1,062.50	
Check No. 434 Aug. 6, 1934, $1.00; and check No. 436 Nov. 12, 1934, $1.17 (included in last year's disbursements but outstanding as of last year's bank balance; checks deducted from this year's bank balance)	2.17	
Balance on hand in bank, as of November 23, 1935 savings (includes contribution to Endowment Fund $1,000.)	2,502.70	
Balance on hand in bank, as of November 23, 1935, checking	56.37	
Total		$3,689.39

Submitted by

A. G. McCALL,

Executive Secretary, American Organizing Committee, and
Assistant Treasurer, American Society of Agronomy.

RECORD OF PROCEEDINGS OF FIRST INTERNATIONAL CONGRESS OF SOIL SCIENCE

Proceedings on hand in storage with The Rumford Press, Concord, N. H., as of Nov. 15, 1934	930 sets
Sold during the period November 16, 1935 to November 23, 1935, inclusive	12 sets
Remaining in storage as of November 23, 1935	918 sets

12 sets distributed as follows:

2 sets at $ 5.50
3 sets at 10.50
7 sets at 11.50
1 Vol. IV only at $2.50

Collections as follows:

2 sets at $ 5.50	$11.00	
4 sets at $10.50 (includes 1 set ordered last year and not paid until this year)	42.00	
5 sets at $11.50	57.50	
1 set at $10.00 (a 1931 order not paid until this year; former price)	10.00	
1 Vol. IV only	2.50	
Total		$123.00

Submitted by,

A. G. McCALL,

Executive Secretary, American Organizing Committee, and
Assistant Treasurer, American Society of Agronomy.

AUDITING COMMITTEE

Dr. Richard Bradfield, *Chairman*, reported that the Auditing Committee had examined the books and vouchers of the Treasurer and the Assistant Treasurer and found them correct. The report was adopted as follows:

The accounts of the Treasurer and Assistant Treasurer have been audited and approved.

H. K. WILSON
R. BRADFIELD, *Chairman*

REPORT OF THE SECRETARY

The report of the Secretary was presented and accepted as follows:

I beg to submit herewith my report as Secretary for the year November 1, 1934, to November 25, 1935, as follows:

Membership changes 1934–1935:			
Membership, last report			868
New members, 1935		168	
Reinstated members		35	
Total increase		203	
Dropped for non-payment of dues	61		
Resigned	14		
Died	5		
Total decrease	80	80	
Net increase		123	123
Membership, November 25, 1935			991
Subscriptions:			
Subscriptions, last report			538
New subscriptions, 1935		111	
Subscriptions dropped		110	
Net increase		1	1
Subscriptions, November 25, 1935			539

MEMBERSHIP BY STATES AND COUNTRIES

Alabama	8	Missouri	20
Arizona	13	Montana	9
Arkansas	7	Nebraska	24
California	39	Nevada	1
Colorado	22	New Hampshire	1
Connecticut	11	New Jersey	17
Delaware	3	New Mexico	10
District of Columbia	79	New York	39
Florida	13	North Carolina	17
Georgia	11	North Dakota	11
Idaho	7	Ohio	39
Illinois	40	Oklahoma	18
Indiana	23	Oregon	14
Iowa	40	Pennsylvania	22
Kansas	41	Rhode Island	7
Kentucky	11	South Carolina	8
Louisiana	15	South Dakota	8
Maine	7	Tennessee	6
Maryland	16	Texas	40
Massachusetts	10	Utah	11
Michigan	10	Vermont	2
Minnesota	25	Virginia	19
Mississippi	6	Washington	19

West Virginia	13	Germany	4
Wisconsin	27	Greece	2
Wyoming	4	Honduras	2
Hawaii	11	India	11
Philippine Islands	2	Italy	1
Porto Rico	1	Japan	6
Africa	8	Jugoslavia	1
Argentine	4	Mesopotamia	1
Austria	1	New Zealand	1
Brazil	2	Poland	1
British West Indies	1	Scotland	1
Canada	20	Siam	1
China	16	Spain	1
Cuba	3	Sweden	1
Denmark	2	Switzerland	1
Egypt	1	Turkey	1
England	3	Uruguay	1
Finland	1	U. S. S. R.	6
Total			991

MEMBERSHIP BY YEARS OF ELECTION

1908 Charter	26	1922	33
1908	8	1923	22
1909	3	1924	29
1910	13	1925	60
1911	21	1926	47
1912	12	1927	38
1913	13	1928	35
1914	10	1929	69
1915	17	1930	45
1916	24	1931	52
1917	11	1932	39
1918	10	1933	37
1919	8	1934	87
1920	23	1935	168
1921	31		
Total			991

TOTAL MEMBERSHIP BY YEARS

1908	121	1918	509	1927	767
1909	129	1919	473	1928	823
1910	176	1920	436	1929	906
1911	236	1921	592	1930	943
1912	295	1922	643	1931	963
1913	349	1923	561	1932	949
1914	397	1924	577	1933	904
1915	471	1925	646	1934	868
1916	586	1926	700	1935	991
1917	652				

Submitted,
P. E. BROWN, *Secretary*.

FELLOWS

Vice-president R. M. Salter announced the Fellows-Elect and presented them with diplomas. Those honored were Dr. Richard Bradfield, Dr. C. E. Millar, and Prof. A. C. Arny. (See pages 1007 to 1008 of this number of the JOURNAL.)

ANNUAL DINNER

The annual dinner of the Society was held on Thursday, December 5, at 6:30 p. m. at the Stevens Hotel with 189 in attendance. The presidential address of Dr. H. K. Hayes was given at the dinner.

NEW BUSINESS

Upon motion of Dr. A. G. McCall, which was carried, he was authorized to send 100 sets of the *Proceedings* of the First International Soil Congress to the Secretary of the International Society for his use.

REPORT OF THE NOMINATING COMMITTEE

Dr. A. L. Patrick presented the report of the nominating committee and upon motion the report was adopted and the following officers declared elected for the next year: F. D. Richey, *Vice-president,* W. H. Pierre and T. E. Odland, representatives of the Society on the Council of the A.A.A.S. R. M. Salter automatically succeeded to the Presidency and H. B. Sprague and W. A. Albrecht were announced as elected to the chairmanships of the Crops and Soils Sections, respectively.

Meeting adjourned.

P. E. BROWN, *Secretary.*

OFFICERS OF THE SOCIETY FOR 1936

President, R. M. Salter, Wooster, Ohio.
Vice-President, F. D. Richey, Washington, D. C.
Chairman, Crops Section, H. B. Sprague, New Brunswick, N. J.
Chairman, Soils Section, W. A Albrecht, Columbia, No.
Editor, J. D. Luckett. Geneva, New York.
Secretary-Treasurer, P. E. Brown, Ames, Iowa.

AGRONOMIC AFFAIRS

MINUTES OF THE 1935 BUSINESS MEETING FOR THE CROPS SECTION

The meeting was called to order by Chairman R. D. Lewis. Dr. Lewis invited attention to the proposed reorganization of the Soils Section of the American Society of Agronomy. It was emphasized that this provides for continuation of close association of soils workers with crops workers. The question was raised as to the advisability of reorganizing the Crops Section along some lines similar to those being completed by the Soils Section. Dr. Lewis suggested that a study should be made of this matter.

F. D. Richey moved that the incoming committee of the Crops Section study this situation, or appoint a committee to make this study, using a method of canvassing members of the American Society of Agronomy and preparing a report similar to that used by the committee of the Soils Section. Motion seconded and passed.

Report of the Nominating Committee appointed by Chairman Lewis was presented by F. B. Bussell. Nominations for the Crops Section Committee for the coming year named O. S. Aamodt of Wisconsin, A. M. Brunson of Kansas with H. B. Sprague of New Jersey as Chairman. The report was accepted. It was moved by Dr. M. A. McCall that the Chairman cast a unanimous ballot for the nominees. The motion was seconded and passed.

Upon motion, the meeting was adjourned to make way for the regular programs. The crops programs arranged by the Crops Section Chairman included three half-day programs with a total of 28 papers and two round-table discussion groups on corn hybrid production and distribution and forage crop improvement, respectively, with 19 persons scheduled to present reports.—H. B. SPRAGUE, *Secretary.*

THE REPORT OF THE JOINT COMMITTEE ON SOIL SCIENCE REORGANIZATION

THE report of the Joint Committee on Soil Science Reorganization was presented before the joint meeting of all interested in soil science on December 4 at the Stevens Hotel, Chicago, Ill., in the same form in which it was published in the November issue of the JOURNAL. Copies of this report were mimeographed and mailed to every American member of the American Soil Survey Association and the American Society of Agronomy early in November. A questionnaire requesting information necessary for the formulation of a satisfactory solution to the problem was attached to the report. Replies were received from 241 members of the A. S. A. who indicated that they were primarily interested in soils and from 149 members of the A. S. S. A. These replies represent approximately 50% of the men interested primarily in soils in both organizations. A summary of the replies received from the members of the two organizations is tabulated below.

SUMMARY OF REPLIES TO THE QUESTIONNAIRE ON SOIL SCIENCE REORGANIZATION

(Expressed as percentage of replies received by November 29)

Question		A. S. A.*	A. S. S. A.†
1. Are you interested primarily in			
Soils only?		44	61
Soils and Crops?		56	39
2. Are you in favor of a single soil science organization in the United States?	Yes	92	95
	No	8	5
3. Do you feel that a close affiliation between Soils and Crops groups should be maintained?	Yes	90	85
	No	10	15
4. Do you favor a merger of the existing Soils Organizations of the general type proposed?	Yes	98	95
	No	3	5
5. Would you favor the publication of a volume of Proceedings to include papers presented at the annual meeting?	Yes	89	91
	No	11	9
6. Would you subscribe for such a volume of 1936 Proceedings if it could be published for $4.00–$4.50?	Yes	85	91
	No	15	9
7. Would your subscription to the Proceedings prevent your subscription of the JOURNAL?	Yes	17	10
	No	83	90
8. What name would you prefer for this Soil Science Organization?			
Am. Assn. of Soil Scientists		15	18
Am. Soc. of Soil Science		51	66
Soils Division of A. S. A.		34	16
9. In which of the proposed Soil Science Sections would you be interested?			
Physics		45	51
Chemistry		64	63
Biology		42	30
Fertility		84	67
Morphology		44	68
Technology		51	61

*Based on 241 replies received from men interested in Soils. Does not include men interested primarily in Crops.

†Based on 149 replies received from a total of 290 members or 51% of total membership.

After prolonged discussion, the proposal "that the A. S. S. A. and the Soils Section of the A. S. A. unite to form a single organization which shall be called the American Society of Soil Science" was approved at the joint meeting by a vote of 88 to 10. The balance of the report was approved with only slight modification and referred to the A. S. S. A. and the Soils Section of the A. S. A. for ratification. The action taken at the joint meeting was unanimously ratified by the A. S. S. A. at a called business meeting on December 5 and at the regular business meeting of the Soils Section of the A. S. A. on the same date. Each organization reappointed its two representatives on the joint reorganization committee and instructed this committee to draft a constitution for the proposed American Society of Soil Science in accordance with the principles already approved. Copies of this constitution were ordered to be brought to the attention of the members of both organizations in advance of the next annual meeting so that the final action necessary to put the plan in operation can be taken at the 1936 annual meeting. A mail ballot on this constitution was requested in the A. S. S. A. A second joint committee was appointed to formulate editorial policies for the proposed *Proceedings.*

NEWS ITEMS

H. W. BENNETT was recently appointed Associate in Agronomy, Forage Crops, Mississippi State College. He will devote his time to research, primarily with the selection and breeding of forage and soil improving crops.

I. E. MILES was recently appointed Associate in Agronomy, Soils, Mississippi State College, where he will devote half of his time to the teaching of Soils and half to research work in the relative symbiotic nitrogen fixation of several legumes.

THE AMERICAN POTASH INSTITUTE, INC., is announcing the appointment of R. G. Pridmore as Assistant Agronomist at its headquarters in the Investment Building, Washington, D. C. Mr. Pridmore was for the past 5 years Assistant Agronomist on the staff of the Georgia Agricultural Experiment Station.

H. M. BAINER has been appointed General Agricultural Agent for the Panhandle and Santa Fe Railway Company with headquarters at Amarillo, Texas.

J. H. CHRIST, Superintendent of the Sandpoint Idaho Experiment Station, has resigned to become Agronomist with the Soil Erosion Service, Colorado Springs, Colo. He has been succeeded by Ralph H. Knight, a graduate of the University of Idaho.

H. W. HULBERT, Agronomist and Head of the Department of Agronomy, University of Idaho, has resigned effective January 1, 1936, to become associated with the Mark Means Company, Seedsmen of Lewiston, Idaho. Mr. Hulbert has been connected with the Idaho Experiment Station since 1917.

M. J. BUSCHLEN, a graduate of Michigan State College, has been appointed Field Superintendent in Agronomy at the Idaho Station.

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